Development of Thermally-Enhanced Walleye Aquaculture

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EXECUTIVE SUMMARY

The culture of walleye in Minnesota can be enhanced by the use of heated waters. Wild-caught walleye fingerlings were maintained in the Aquaculture Research Facility at Minnesota Power's Clay-Boswell Plant. These fingerlings were subsequently induced to feed on a pelleted dry feed and to grow, increasing their size 8.8 times. Fingerling mortality within the facility after conversion to dry diet was minimal. Feed conversion (food fed to body weight increase) ranged from 2.2 to 3.2 over the project's duration.

Growth predictions from walleye bioenergetics models, developed for each of the strains in the Aquaculture Research Facility, were extremely close to actual growth in the facility (within 2%). Because of the short duration of the project, it is too early to assess the walleye model's ability to predict mortality and food conversion efficiency. However, initial inspection suggests that it may predict walleye mortality (after fish have switched to dry diet) quite well, but does not predict food conversion well at this point. The walleye bioenergetics model appears to provide a means of detecting growth differences in different strains of walleye, which could be extremely valuable in choosing faster growing strains for future culture.

INTRODUCTION

A major obstacle in the development of aquaculture in northern Minnesota is the slow growth of cultured species in cold water. The primary growing season in this area may only be 4-5 months. The growing season can be extended and growth rates can be increased in northern climates by heating the water. However, costs associated with heating the water of a culture facility to optimal growth temperatures are often prohibitive (see McDonald et al. 1987).

Since the spring of 1985, using the thermal and water resources of Minnesota Power's Clay Boswell Steam Electric Station (CBSES), channel catfish, rainbow trout, Atlantic salmon (Minnesota Power and Minnesota Department of Natural Resources Report 1986), and whitefish (J. Ringle, Leech Lake Tribal Fisheries Biologist, personal communication) have been successfully reared in the Aquaculture Research Facility. Economic scaling of costs involved with growing Atlantic salmon and catfish suggests that a moderate return on investment (assuming significant public funding to offset capital) could be obtained on a full scale aquaculture operation for these species (P. Johnson, Minnesota Power, personal communication). However, market saturation of Atlantic salmon by the early 1990's and the existing southern U.S. catfish aquaculture infrastructure may seriously hinder market penetration for new growers of these species.

Thermally-enhanced aquaculture of walleye in Minnesota could develop into a major, new growth industry. Demand for walleye will continue due to increasing demand for walleye stocking in sports fisheries and increasing consumer demand (Skurla and Van Hale 1987). The sport fishing and consumer market already recognizes the walleye as a high value fish.

The walleye is an appealing aquaculture species because of its high market value and because it can be marketed at several different life stages. Currently, the existing markets for walleye are: 1) as eggs for hatcheries (at $400-$1000 per quart), 2) as fry for stocking (at $16-$25 per 1000), 3) as 2" fingerlings for stocking (at $0.15-$0.25 apiece), 4) as wholesale round weight fish (at $1.25-$3.00 per pound), and 5) as a fillet for the retail consumer (at $3.25-$6.00 per pound) (Skurla and Van Hale 1987).

Simulations of walleye growth in facilities with heated and unheated waters, based on a walleye bioenergetics model (McDonald unpublished data), suggests that in the heated water facility growth would be 4-fold faster, survival 3-fold greater, and food conversion 30% better. Using heated waters appears to offer a substantial benefit in producing a marketable product faster and more efficiently than could be obtained with current (unheated) techniques. Also, this opens possibilities for producing multiple walleye crops during the year (varying temperature to speed up or retard the growth of the fish), and to bring the particular product to market at the most profitable time.

To develop the full potential for walleye culture, both the biological and economic opportunities and constraints must be examined (see Skurla and Van Hale 1987). The purpose of this research project was to establish the feasibility of growing walleye in an enhanced thermal environment in the Aquaculture Research Facility on artificial feed and to assess the utility of a walleye bioenergetic model in predicting growth, mortality, and feed conversion.

WALLEYE CULTURE AT THE AQUACULTURE RESEARCH FACILITY

Initially, walleye converted to artificial feed were to be purchased from a commercial dealer. However, due to the late start-up date of the project (Aquaculture Research Facility became fully operational 21 September 1987), insufficient converted walleye were available to meet the goals of the project. Therefore, it was decided to purchase the smallest walleye fingerlings available and convert them to artificial feed as part of the project at the Aquaculture Research Facility.

Fingerlings were delivered to The Aquaculture Research Facility on 30 Sept 1987 (4000-5000 from Golden Pond Fisheries, Erskine, MN). Prior to delivery, water temperature at the Aquaculture Research Facility was lowered to 64° F (as low as possible, using ambient river water) in an attempt to reduce the thermal stress on the fingerlings (taken from 52° F water). A 17% mortality from stress due to handling, transportation, and temperature change occurred within one day. A second group of 1200-1500 walleye fingerlings were donated to the project by Leech Lake Reservation's Department of Fisheries, and delivered 2 October 1987. The total number of fingerlings delivered to the facility was approximately 6249.

Within the first nine days of operation, 2053 walleye fingerlings (33%) were lost to various stocking stresses and to a subsequent fungal infection. Within the month, losses had begun to decline and there was evidence of acceptance of the artificial feed by the fingerlings. Unfortunately, on 16 Oct 1987 the single power generation unit was shut down and the thermal regime in the Aquaculture Research Facility was lost and had to be re-established over the next 5 days. No walleye feeding occurred during this time, and this likely increased mortality and decreased growth either directly through thermal stress and increased susceptability to disease or through the loss of conversion of some walleye fingerlings to artificial feed.

By the end of October, the Aquaculture Research Facility's operation had been established as a 6-day feeding schedule (no Sunday feeding - due to availability of personnel), a 16 hr light - 8 hr dark cycle, and a water temperature of 68^{o}-70^{o} F. At that time, one of the project objectives had already been accomplished, wild-caught walleye fingerlings had been induced to feed on a dry pelleted diet.

Starvation mortalities continued into November, accounting for the relatively low 67% survival rate for November (42% overall). During this month a second research objective was met, when the walleye fingerlings were found to grow on the artificial pelleted diet in the Aquaculture Research Facility.

During December, the monthly mortality rate dropped to 3.1% as starvation mortality ended, and with the prophylactic use of tetracyclene for disease control. Sufficient data on walleye growth in the Aquaculture Research Facility was available during this month to allow bioenergetic model predictions for future growth (see next section).

In January all walleye were counted and 2474 still remained (only 4 fish were lost during this month). Because of continued growth, the walleye were redistributed at approximately equal densities in six tanks. However, strain integrity was maintained to allow examination of the possible growth differences (suggested by the walleye bioenergetic model, see next section).

Walleye fingerlings continued to show very low mortality, very good growth, and a reasonalble mean conversion efficiency over the final three months of the project (Table 1, Appendix C). Over the entire project 39.4% of the walleye survived. After walleye had been converted to the pelleted feed (through November), survival rate was 97%. During their seven months in the Aquaculture Research Facility (to 17 April assessment), the walleye have grown from a mean individual size of 0.015 lb to 0.133 lb (range 0.115 lb to 0.172 lb). This is an 8.8 fold increase in size, during a period when walleye in the wild show no growth. Feed conversion (ratio of food fed to fish flesh added) was not able to be calculated until December due to the high feeding rates (necessary to induce feeding on dry pellets) and mortality rates relative to growth increases. Feed conversion in December was 2.2, but the conversion efficiency decreased as the fish increased in size (3.2 in April).

The goals of the project at the Aquaculture Research Facility have been very successfully met. Wild-caught walleye fingerlings (large at 75-100 mm) can be established in the Aquaculture Research Facility, they can be induced to feed on an artificial dry pelleted food, and they can be grown extremely rapidly during winter months, when there is no growth in the wild.

Table 1. Monthly weight (lb), % monthly weight increase, food conversion (food fed/weight gain), and % monthly mortality for walleye in thermally-enhanced culture at the Aquaculture Research Facility.

Date	Weight	% Wt Gain	Conversion	% Mort
20ct87	0.015	-	-	-
17Nov87	0.027	80	-	58
17Dec87	0.045	67	2.2	3
17Jan88	0.062	38	2.7	0.2
17Feb88	0.082	32	2.6	0.3
17Mar88	0.110	34	2.7	0.004
17Apr88	0.133	21	3.2	0.2

WALLEYE BIOENERGETICS MODEL

The walleye bioenergetics model was developed from a generalized bioenergetics model (Hewett and Johnson 1987), to predict changes in growth or food consumption under different thermal or cultural regimes. The general model has been used extensively, and successfully, for predicting consumption or growth of a variety of species in natural systems (e.g., Kitchell et al. 1977, Kitchell and Breck 1980, Stewart et al. 1981, Cochran and Rice 1982, Rice and Cochran 1984), and has recently been used for estimating growth of chinook salmon under various culture conditions (McDonald et al. 1987). Bartell et al. (1986) have examined the sensitivity of this model to individual parameter perturbation to identify key variables.

Physiological parameters for the walleye model were taken from Kitchell et al. (1977) for walleye in Lake Erie. Data from actual conditions in the Aquaculture Research Facility were used to refine the model, and mean walleye growth rates from the operation of the facility were used for initial prediction in December and January. The model was used to predict individual walleye weight when fed six and seven days a week. Expected walleye growth during this period under ambient field conditions is also shown. Walleye growth for January was overestimated by 7% by the model. It was felt that the discrepency was due to differences in the growth rates of the two strains (Erskine and Leech Lake) present in the facility. Subsequently, models were developed for each strain and growth predicted through 17 May 1988 (Fig. 1, Table 2). Subsequent model predictions for walleye growth at the Aquaculture Research Facility were extremely close

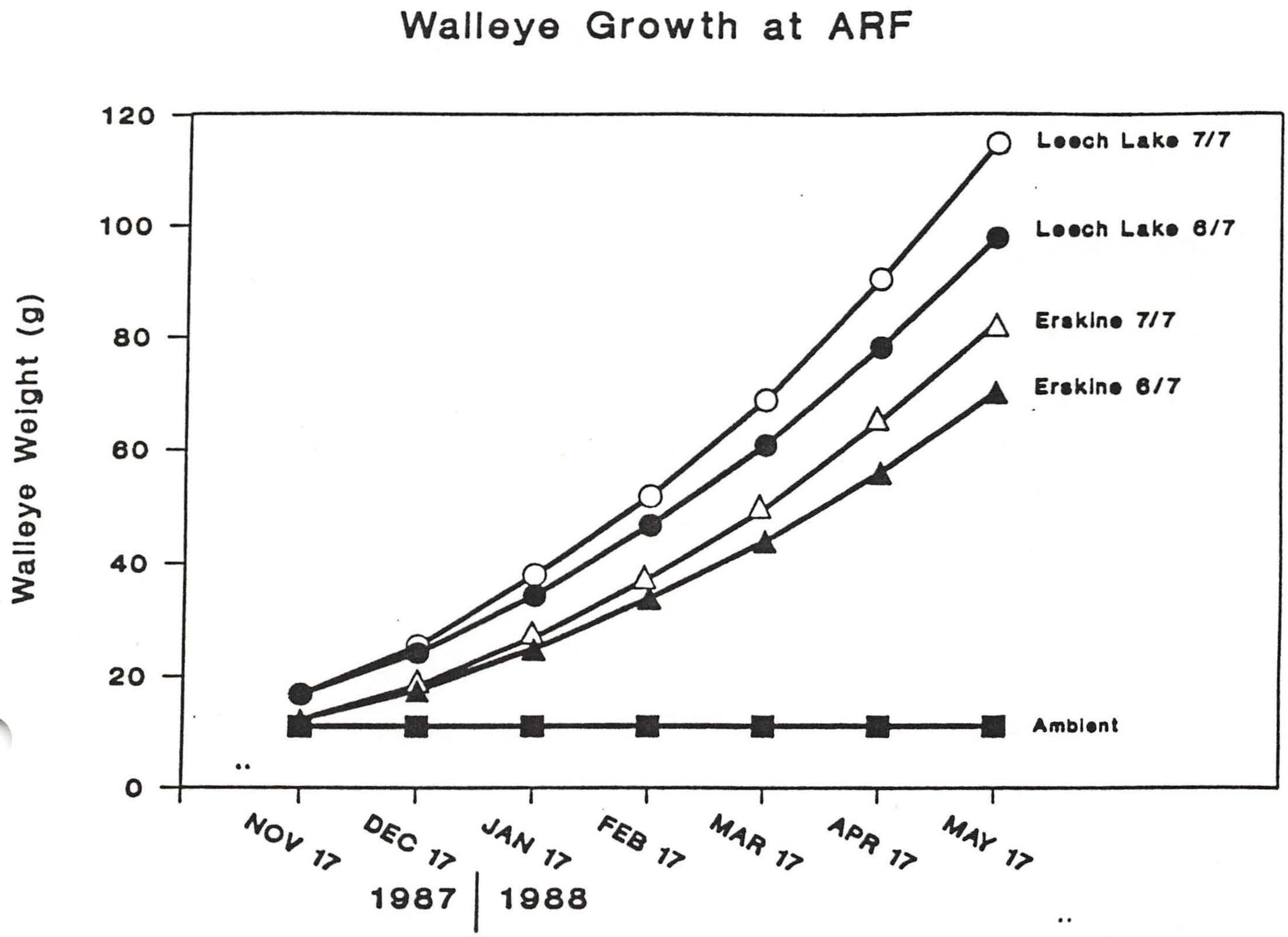

Figure 2. Predicted size of Leech Lake and Erskine walleyes in the Aquaculture Research Facility from the bioenergetics models' projections when fed 6 out of 7 days and when fed 7 days/week. Ambient winter growth is also shown. <u>Observed growth in the Aquaculture Research Facility lies on the predicted 6/7 lines for both strains.</u>

OBSERVED AND PREDICTED WALLEYE GROWTH AT THE
AQUACULTURE RESEARCH FACILITY

Date	Leech Lake observed	Leech Lake predicted 6/7	Leech Lake predicted 7/7	Erskine observed	Erskine predicted 6/7	Erskine predicted 7/7	Ambient
Nov17	16.6	16.8	16.8	12.1	12.3	12.3	11.1
Dec17	23.9	24.3	25.4	19.2	17.7	18.5	11.1
Jan17	35.9	34.4	38.0	24.5	25.0	27.0	11.1
Feb17	46.9	46.9	51.9	33.9	34.0	37.7	11.1
Mar17	62.0	60.8	68.9	43.8	44.0	49.8	11.1
Apr17	77.8	78.3	90.4	53.8	56.5	65.2	11.1
May17		98.0	115		70.5	82.7	11.1

Table 2. Observed walleye weights (g) for both Erskine and Leech Lake strains when fed six out of seven days (standard practice at the Aquaculture Research Facility during the course of this work). Predicted walleye weights (g) from the bioenergetics models for both strains when fed on 6/7 and 7/7 feeding regimes. Walleye growth at ambient winter water temperatures is also shown.

to observed (within 2% for both the Leech Lake and Erskine strains). The model's output also suggests that the Erskine strain of walleye may be slower growing, even after adjusting for size differences.

The bioenergetic models for each strain of walleye have predicted the observed growth through the end of the project extremely well. If fish were allowed to remain in ARF under similar conditions for one year from the 17 Feb 1988 assessment, the bioenergetics model predicts that the Leech Lake strain fed 7 days a week would be 1.2 lbs. A Leech Lake strain fed six days/week would be 0.93 lb in this time. An Erskine strain fed 6/7 would weigh 0.65 lb, and fed 7/7 would weigh 0.84 lb, at the end of one year. In comparison, it would take a St. Louis River walleye approximately 6-8 years to reach 1 lb.

Since fingerlings were re-distributed within their tanks at known densities during January, estimates of mortalities and food conversion could not be predicted until March. The model predicted a total mortality of 7 walleye during March, and only 1 occurred (0.3% error relative to the entire population). For April the general prediction accuracy improved to 0% error for the Leech Lake strain and 0.2% for the Erskine strain. It is too early to tell about the general mortality prediction accuracy of the model, but the results are promising.

The model's predicted walleye feed conversion efficiency was considerably lower than that actually observed in ARF. The model predicted a 3.7 conversion (lbs feed/lb fish) for the Leech Lake strain and a 4.2 for the Erskine strain, while the mean observed values for this period (Mar-Apr) was between 2.68 - 3.22. This could be due to an underestimate in the actual caloric value of the feed, but further research will be required to improve the model's estimates.

Overall, the model predicted the growth and mortality of the walleye grown in thermally-enhanced culture extremely well. Also, the walleye bioenergetic models may provide a means of detecting growth differences between strains, which may be a very important tool for aquaculturists in the future.

The performance of this project complies with all project requirements.

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Appendix A

Monthly Reports

Development of Thermally-Enhanced Walleye Aquaculture

Monthly Report for September 1987

Principal Investigator: Michael McDonald, Ph.D.

Initially, walleye already converted to artificial feed were to be purchased from a commercial dealer. However, the dealer was unable to convert enough of his walleye to meet project needs. Iowa DNR's Rathbun Fish Hatchery was then contacted to obtain converted walleye. However, the hatchery personnel considered their converted walleye too valuable to their stocking programs to provide this project with the necessary experimental fish. It was then decided to purchase the smallest walleye fingerlings available and convert them to artificial feed at ARF. Fish obtained through Leech Lake Reservation's Dept. of Fisheries would also be used to supplement this supply. Although there is increased risk involved with this late season conversion of walleye fingerlings, the potential gain of useful project information is also increased sufficiently to make the risk acceptable.

Artificial feed for the walleyes was obtained from Glencoe Mills and delivered to ARF on September 14. The ARF facility became fully operational during the week of September 21. Approximately, 5000 four inch walleye fingerlings were obtained from Golden Pond Fisheries (Erskine, MN) and delivered to ARF on September 30. Prior to this time, water temperature at ARF was lowered to 64^{o} F (as low as possible - ambient river temperature) to reduce thermal stress on walleye fingerlings (taken from 52^{o} F water). A 17% mortality of this group occurred within 1 day, likely due to stress from handling, transportation, and temperature change. Delivery of an additional 1500 walleye fingerlings from Leech Lake Reservation's Dept. of Fisheries was expected (and occurred) on Friday October 2.

During this period the walleye bioenergetics model was further refined and partially parameterized for expected conditions at ARF. A hard disk drive was obtained (no cost to MP) and the model was transferred to it. This will increase the capacity of the model and will speed modelling simulations.

Development of Thermally-Enhanced Walleye Aquaculture

Monthly Report for October 1987

Principal Investigator: Michael McDonald, Ph.D.

At the end of October we had approximately 3900 walleye fingerlings remaining from an initial starting population of about 6250. The >60% survival of these fingerlings to this point is excellent, especially considering the large initial size of the fingerlings and the initial stocking stresses. We had a large scale fungal infection shortly after stocking, but this was rapidly controlled by administering antibiotics to the tank water. We then discontinued antibiotic use, and since then, we have been treating tanks daily with a salt solution as a prophylactic. Antibiotics (tetracycline) are used on an as needed basis, when fungal infections are observed.

During October, the walleye fingerlings began to eat the artificial feed and are now consuming the intermediate W-16 diet pellets (3/32"). On Saturday, October 16, at a critical point in the walleye's switch over to artificial feed, the single power generation unit in operation was shut down. Quick action by ARF operators' was taken to temper the fishes slowly (at about 2° F/hr) from facility operational water temperature (68° F) to ambient river temperature (42° F). Unit 3 came back on line on Sunday, and ARF personnel began the process of slowly re-acclimating the walleye to 68° F). Walleye were back at normal temperature by the afternoon of October 20. However, walleye were not being fed during this entire period. This may have resulted in increased mortality from thermal stress, susceptability to disease in the stressed fish, and/or loss of conversion of some fish to artificial feed. This delayed the conversion of the walleye fingerlings to artificial feed, such that the initial conditions for parameterizing the bioenergetics could not be obtained during October. Thus, simulation predictions from the walleye bioenergetic model will be made based on initial conditions taken during sampling in November after the majority of starvation mortality has occurred.

In October, we did succeed in accomplishing one of our research objectives. This was to determine whether large, wild-caught walleye fingerlings could be converted to feeding on artificial food. In examining the feeding tracts from several specimens in tanks at ARF, we have found them to be full of food. Also, the robust condition of most of the remaining fishes and the nature of the fecal matter in the tanks suggests that, we have indeed succeeded in converting these larger walleye.

Current ARF operation has been modified to a 6-day feeding schedule (no Sunday feeding), with a daily 16 hr light and 8 hr dark cycle. Feeding occurs during the low level light period from 4 pm to 8 am. Fish are being fed at an estimated 5% body weight/da. Water temperature has been increased to 70° F, as long as nitrogen supersaturation does not exceed 105%.

Walleye bioenergetics model is now fully operational on the hard disk drive. The model has been further refined, and now only requires the initial ARF fish parameters to begin predictive simulation. Growth predictions from the model will be compared to actual observed growth for November.

Development of Thermally-Enhanced Walleye Aquaculture

Monthly Report for November 1987

Principal Investigator: Michael McDonald, Ph.D.

At the end of October we had 3904 walleye fingerlings, and at the end of November we had 2611 walleye remaining. This is a 67% survival rate for November. This is lower than we would have liked, but we continued to have starvation mortalities throughout November. Under these conditions, this survival rate is reasonable, and mortalities dropped considerably by the end of November. In early November, walleyes in the initial 3 tanks were divided among 6 tanks. At this time the average fish weighed 11.1 g. Thirteen days later, from a subsample of fishes from three of the tanks, the average fish weighed 13.6 g (range 11.11-16.86 g). This is a 22.6% increase in body weight in less than 2 weeks in feeding fishes. Using a starting weight of 11.1 g, the current bioenergetics model predicted a weight of 15.6 g at the end of this 13 da period. While this is higher than the average observed weight, it does fall within the observed range. This suggests that with further actual data from the facility to parameterize and refine the model, that the model can be an efficient predictor of walleye growth under existing ARF conditions.

During November, the walleye fingerlings continued to eat the commercial W-16 diet pellets (3/32"). Feeding rate was maintained at 5% body weight/da. Feeding regime consisted of fish being fed for 16 hrs/da, 6 days/wk. Temperature was maintained at 69° F.

Fungal infection continued to be a problem in November. The use of antibiotics was required every 10-14 da. We have since gone to the prophylactic use of antibiotics, treating fishes for 4 da/wk. This is a more expensive treatment than has been previously used, but we feel it is necessary to maintain the fish in good health. In the future, the installation of an ultraviolet disinfection system on the incoming Mississippi River water, would likely reduce the need for continued antibiotic application.

In November, we succeeded in accomplishing several of our research goals. We were able to induce large, wild-caught walleye fingerlings to feed, and <u>grow</u> in ARF. Also, our predictions of initial walleye growth from the bioenergetics model appear to agree quite well with the observed growth, especially at this early stage of model refinement. Based on the current model, the predicted average weight of a walleye by the end of December is 30 g. The model is currently being refined based on the new data, and a revised December walleye growth estimate will be made.

Much of the successful rearing of the walleye in ARF to date, has been determined by the high quality of the MP personnel at ARF. They have been exceptional at responding to emergencies (real and otherwise) at all hours of the day and night, seven days a week. The should be commended for their diligence.

Development of Thermally-Enhanced Walleye Aquaculture

Monthly Report for December 1987

Principal Investigator: Michael McDonald, Ph.D.

At the end of November we had 2611 walleye fingerlings, and at the end of December we had 2529 walleye remaining. Only 82 fish were lost during this period for a monthly mortality rate of 3.1%. Some disease and starvation mortalilty continued into the first week of December. With the prophylactic use of tetracyclene for disease control on the fingerlings, mortalities in the last three weeks of December were reduced to 26 fish.

Fingerling walleye at ARF weighed an average of 20.81 g on December 17, 1987. This is an increase of 7.21 g from the previous measurement on November 17, 1987. This is a weight increase of 53% in one month.

Using the November 4, 1987 fingerling weight (11.1 g) as the initial weight of the fingerlings and the November 17, 1987 weight as another data point, the current walleye bioenergetics model was used to predict a weight of 20.85 g for fingerlings on December 17, 1987. The average of the observed weights for the fingerlings in ARF at this time was 20.81 g (Fig. 1, Table 1). Under ambient field temperature conditions during this period, walleye fingerlings would show no growth (Fig. 1, Table 1). If the fingerlings were maintained under ARF conditions, but fed 7 days a week (rather than the current 6 days), predicted fingerling size at this time would have been 28.43 g (Fig. 1, Table 1). The predicted weight of walleye fingerlings, under current ARF regimen, for January 17, 1988 is 30.54 g (Fig. 1, Table 1).

During November, the walleye fingerlings continued to eat the commercial W-16 diet pellets (3/32"). Feeding rate was maintained at 5% body weight/da. Temperature was maintained at 69° F.

Current predictions of walleye growth from the bioenergetics model appear to agree quite well with observed growth. Since disease and starvation have been reduced to current low levels, the necessary data can begin to be acquired to improve the predictive capability of the model for estimating mortality over a growth period, as well as, estimating the feed consumption of the fingerlings over a growth period.

Much of the successful reduction in disease of the walleye in ARF has been due to a conscientious and determined effort on the part of MP personnel at ARF. Their efforts have brought the mortality down to the currrent low levels.

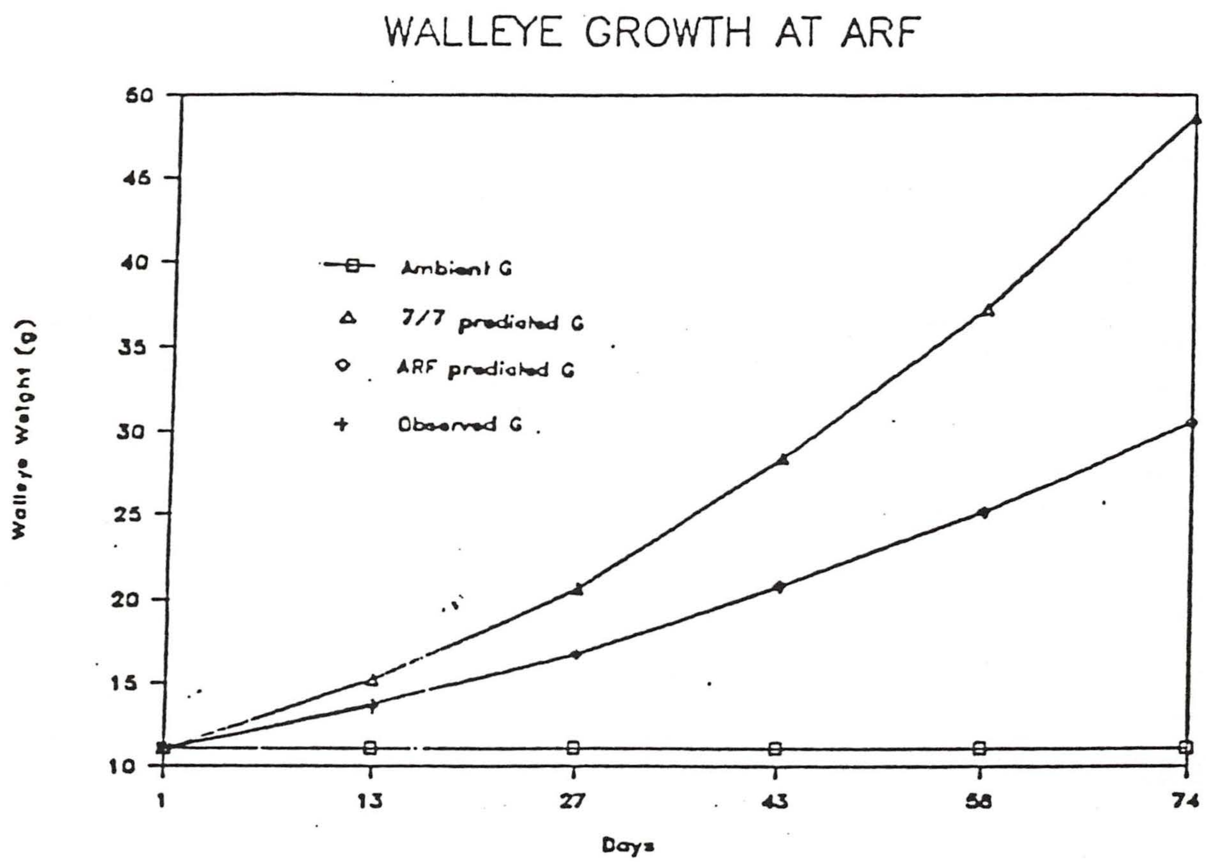

Figure 1. Observed (Observed G) and predicted size of walleyes in ARF starting on November 4, 1987 (Day 1). Predicted walleye sizes are from the bioenergetic model using ambient winter water temperature (Ambient G), current ARF conditions (ARF Predicted G), and at current ARF conditions, but fed 7 days/week (7/7 predicted G).

Date	Day	Amb. G	Obs. G	Pred. G	7/7Pred.
4Nov87	1	11.1	11.1	11.1	11.1
17Nov87	13	11.1	13.6	13.74	15.21
1Dec87	27	11.1		16.76	20.69
17Dec87	43	11.1	20.81	20.85	28.44
1Jan88	58	11.1		25.24	37.29
17Jan88	74	11.1		30.54	48.62

Table 1. Observed (Obs. G) and predicted size of walleyes in ARF starting on November 4, 1987. Predicted walleye sizes are from the bioenergetic model using ambient winter water temperature (Amb. G), current ARF conditions (Pred. G), and at current ARF conditions, but fed 7 days/week (7/7 pred.).

Development of Thermally-Enhanced Walleye Aquaculture

Monthly Report for January 1988

Principal Investigator: Michael McDonald, Ph.D.

We had only 4 walleye mortalities during the month of January. During the period from 20 Jan - 22 Jan, a total count of all the walleye fingerlings in all tanks was made. We have a total of 2474 fish currently in the facility. This is 50 fish less than we previously estimated, but was based on the propagation of a less than 1% error in our initial density estimate. Therefore our actual mortality during the month of January was 0.2%. We have continued our prophylactic use of tetracycline for disease control. (Oxy)Tetracycline has been cleared for use in food fish by the U. S. Food and Drug Administration since 1976 (Meyer, F. P., Schnick, R. A., Cumming, K. B., and Berger, B. L. 1976. Registration status of fishery chemicals. Progressive Fish Culturist 38(3)). As of 1986, it was one of only five chemicals which were registered for use (Stickney, R. R. 1986. Culture of Nonsalmonid Freshwater Fishes. CRC Press).

Fingerling walleye at ARF weighed an average of 28.3 g on January 17, 1988. This is an increase of 7.5 g from the previous measurement on December 17, 1987. This is a weight increase of 36%. The walleye bioenergetics model predicted a weight of 30.5 g for fingerlings on January 17, 1988 (Fig. 1, Table 1). Walleye growth was also predicted for ambient field temperature conditions during this period, and for ARF conditions when fed 7 days a week (rather than the current 6 days). The model overestimated the average walleye growth during this period by approximately 7%. This difference may be due to differences in growth of the two strains currently being used in ARF. The Leach Lake strain's average walleye weight on 17 January was estimated 35.9 g, while the Erskine strain's average fish weight was estimated as 24.5 g. I feel that the previous use of a mean weight for fishes may have introduced some error into the model's predictive capabilities. I intend to begin to develop models for each of these strains to obtain better predictive capabilities and to be able to compare growth rates between the strains for future stock enhancement.

During mid-December, the walleye fingerlings were switched to a 1:1 mix of 3/32" and 1/8" W-16 diet pellets; feeding rate was reduced to 3% body weight/d, because of the larger size of the fingerlings. Temperature was maintained at approximately 69° F.

Walleye fingerlings were redistributed within their tanks, maintaining strain integrity, such that the current densities in the tanks is between 408-420 fish/tank. This will allow better tracking of the feeding and food consumption for use within the bioenergetics model.

The continued successful reduction in mortality of the walleye in ARF has been due to a conscientious and determined effort on the part of MP personnel at ARF. Their efforts on behalf of this project are invaluable.

Date	Day	Amb. G	Obs. G	Pred. G	7/7Pred.
4Nov87	1	11.1	11.1	11.1	11.1
17Nov87	13	11.1	13.6	13.74	15.21
1Dec87	27	11.1		16.76	20.69
17Dec87	43	11.1	20.81	20.85	28.44
1Jan88	58	11.1		25.24	37.29
17Jan88	74	11.1	28.3	30.54	48.62
1Feb88	84	11.1		34.2	56.8
17Feb88	101	11.1		41	72

Table 1. Observed (Obs. G) and predicted size of walleyes in ARF starting on November 4, 1987. Predicted walleye sizes are from the bioenergetic model using ambient winter water temperature (Amb. G), current ARF conditions (Pred. G), and at current ARF conditions, but fed 7 days/week (7/7 pred.).

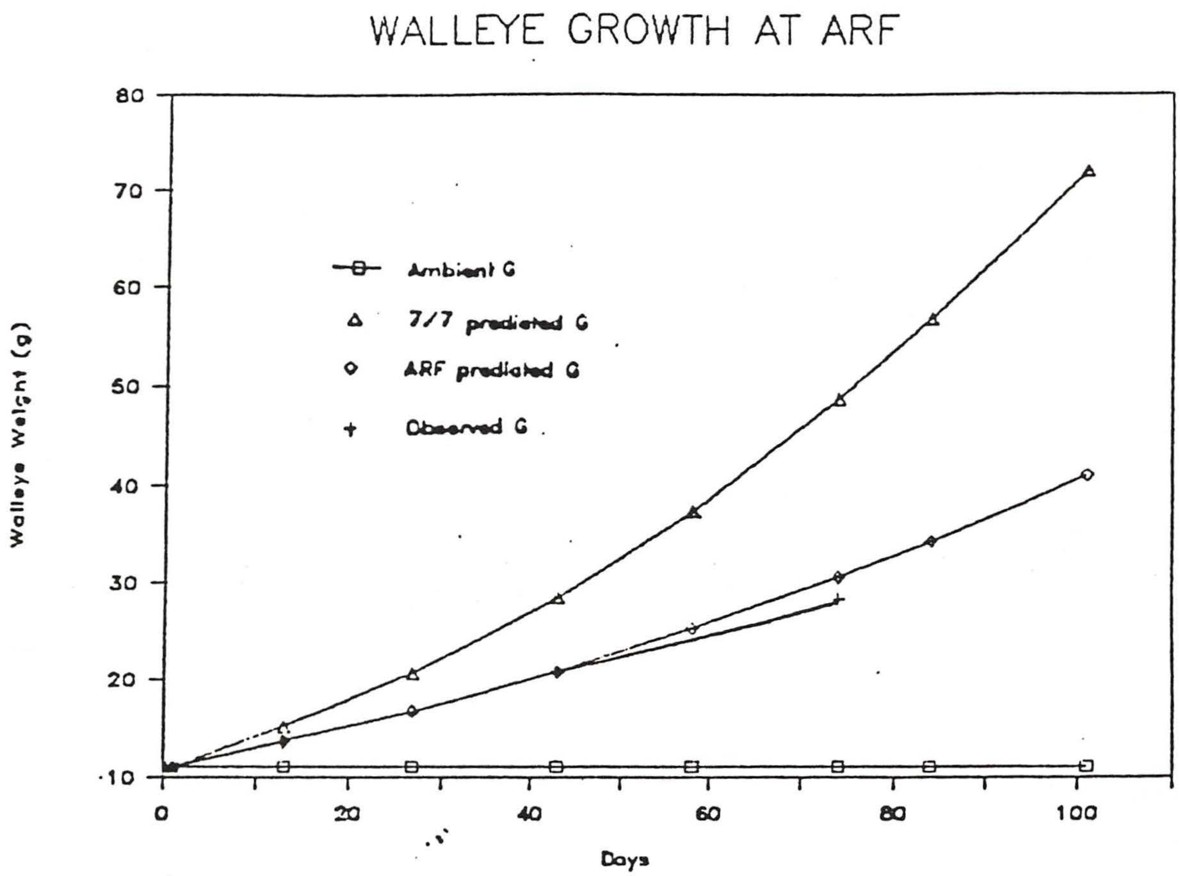

Figure 1. Observed (Observed G) and predicted size of walleyes in ARF starting on November 4, 1987 (Day 1). Predicted walleye sizes are from the bioenergetic model using ambient winter water temperature (Ambient G), current ARF conditions (ARF Predicted G), and at current ARF conditions, but fed 7 days/week (7/7 predicted G).

Development of Thermally-Enhanced Walleye Aquaculture

Monthly Report for February 1988

Principal Investigator: Michael McDonald, Ph.D.

We had only 7 walleye mortalities during the month of February. All walleye mortalities were from the Erskine strain. We have a total of 2467 fish currently in the facility, 816 Leech Lake strain (approximately 1500 initially) and 1658 Erskine strain (approximately 4700 initially). Using recent monthly mortalities, model estimates for monthly mortality for the Leech Lake and Erskine strains are 0.16% and 0.34% respectively.

Fingerling walleye at ARF weighed an average of 38.3 g on February 17, 1988. This is an increase of 10 g from the previous measurement on January 17, 1987; weight increased 26.1%. The walleye bioenergetics model predicted a weight of 41.0 g for fingerlings on February 17, 1988. The bioenergetic model over-estimated the growth during this period by 6.6%. Because of this difference and the observed larger size of the Leech Lake walleye, individual bioenergetic models were developed for the Leech Lake strain and the Erskine strain walleye. The model was re-parameterized using all the currently available data. The models' predictions are given for both strains when fed six and seven days/week; also included was the expected walleye growth during typical winter conditions. Growth was predicted for each month through May 17 (Fig. 1, Table 1). Comparison of growth rates between the strains suggests that the Leech Lake strain may grow approximately 5% faster than the Erskine strain.

Walleye fingerlings continue to be fed a 1:1 mix of 3/32" and 1/8" W-16 diet pellets at 3% body weight/d. Temperature was maintained at approximately 69° F.

Since the walleye fingerlings were redistributed within their tanks at known densities in January, we are still tracking their feeding and food consumption. We intend to have model estimates of food consumption for comparison with actual food used at the facility for the next monthly report.

Following his keynote address at the Minnesota Chapter of the American Fisheries Society Meeting in Grand Rapids, Representative Willard Munger expressed an interest in seeing the results of our research at ARF. After being shown the walleye that we have reared successfully to date, he expressed a great interest in the project and asked if he could bring a group of legislators through the facility. I am currently trying to establish a time when this could be organized.

Observed and Predicted Walleye Growth at ARF

Date	Leech Lake 6/7	Leech Lake 7/7	Erskine 6/7	Erskine 7/7	Ambient
Nov 17	16.8	16.8	12.3	12.3	11.1
Dec 17	24.3	25.4	17.7	18.5	11.1
Jan 17	34.4	38.0	25.0	27.0	11.1
Feb 17	46.9	51.9	34.0	37.7	11.1
Mar 17	60.8	68.9	44.0	49.8	11.1
Apr 17	78.3	90.4	56.5	65.2	11.1
May 17	98.0	114.9	70.5	82.7	11.1

Table 1. Predicted walleye sizes from the bioenergetic model for both the Leech Lake and Erskine strains fed on 6 and 7 days a week. Also, walleye growth at ambient winter water temperature is shown.

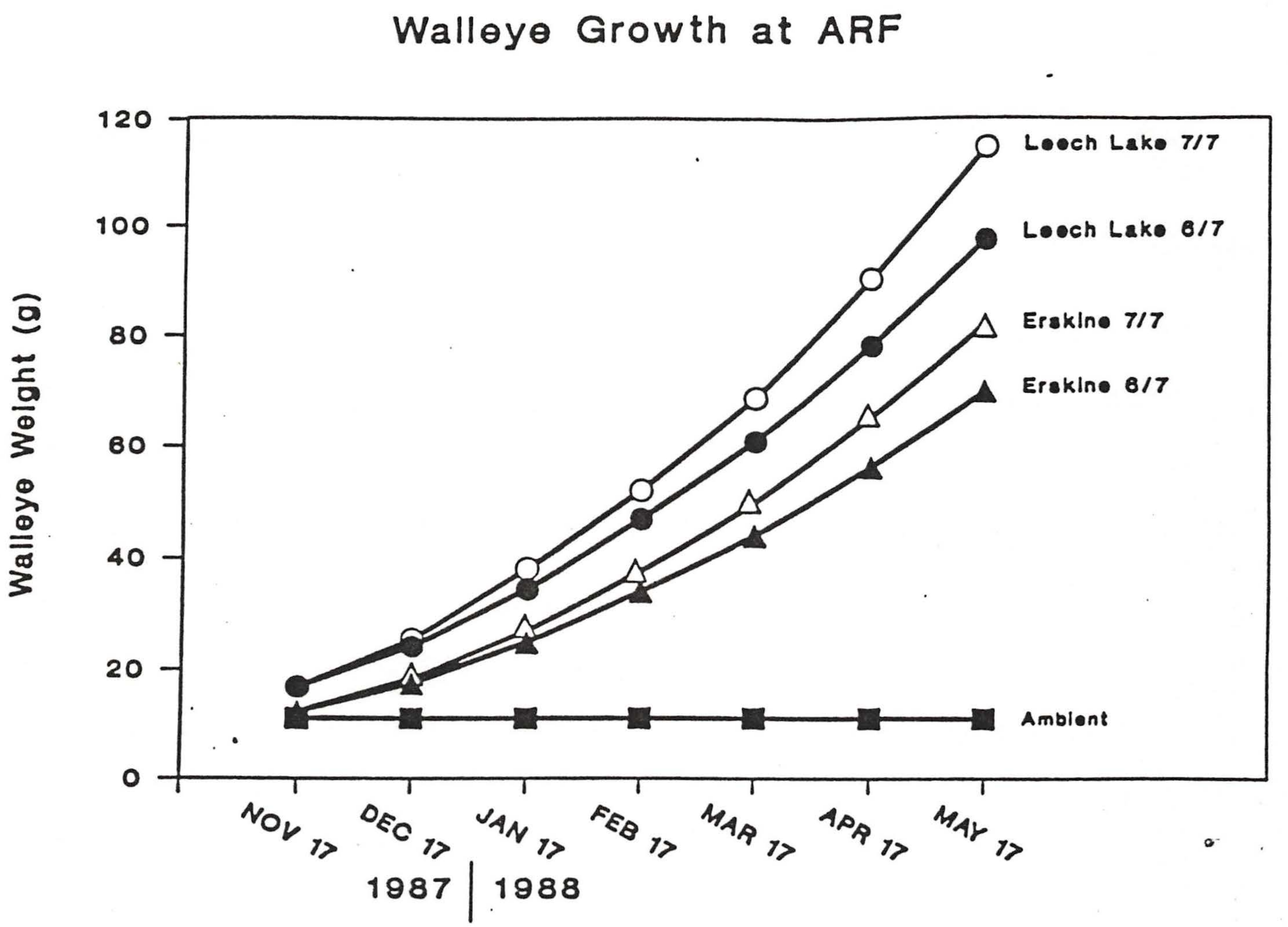

Figure 1. Predicted walleye sizes from the bioenergetic model for both the Leech Lake and Erskine strains fed 6 and 7 days a week. Also, walleye growth at ambient winter water temperature is shown.

Development of Thermally-Enhanced Walleye Aquaculture

Monthly Report for March 1988

Principal Investigator: Michael McDonald, Ph.D.

We had only 1 walleye mortality during the month of March. The single mortality was from the Erskine strain. We have a total of 2466 fish currently in the facility, 816 Leech Lake strain and 1657 Erskine strain walleye. The model predicted one mortality for the Leech Lake strain walleye and six for the Erskine strain. Since this is the first mortality prediction for each strain, it is too early to tell about the general prediction accuracy.

Leech Lake walleye fingerlings at ARF weighed an average of 62.04 g on March 17, 1988. The walleye model predicted an average weight of 60.8 g. This is <2% underestimate by the model. Erskine strain walleye had an average weight of 43.8 g, and the model predicted an average weight of 44.0 g. This is <0.5% overestimate of the growth by the model. Growth predictions for each month through May 17 are shown in Fig. 1 and in Table 1. The model is currently predicting walleye growth at ARF very well.

Leech Lake walleye have been shifted exclusively to a 1/8" pellet diet. Since the Erskine fish are smaller they are currently being fed a 1:2 mix of 3/32" and 1/8" W-16 diet pellets. All fish are currently being fed at 3% body weight/d. Temperature was maintained at approximately 69° F during the period of growth measurement and modeling assessment (until March 17). However, towards the end of March, because of low electrical demand at night and on weekends, the facility was unable to maintain desired flow and water temperature. The ARF staff responded to numerous low temperature alarms, and did an excellent job of ameliorating the problem within the physical constraints of the system, but temperatures have fluctuated and may affect growth during the next month (as well as the accuracy of the model's predictions).

Walleye fingerlings from Leech Lake would have to consume 46.6 lbs of feed per tank to achieve the observed growth based on the bioenergetics model. This is a 1:3.7 feed to fish conversion ratio. Actual feeding levels to these tanks was 76.8 lbs. The difference between projected required consumption and actual feeding levels is due to the necessity of having sufficient feed in the system to assure that the fishes will consume approximately 47 lbs of feed during the month. It was predicted that the Erskine fishes would need to consume 37.7 lbs of feed per tank per month in order to achieve the observed growth (conversion 1:4.2). This suggests that the Erskine strain is slower growing due to less efficient conversion of the pellet feed to fish tissue. The mean feeding rate for the tanks containing Erskine walleye was 55.7 lbs per tank per month.

The predicted size of the walleye on May 17 is 98 g and 70.5 g for the Leech Lake and Erskine fish, respectively. This is less than 1/4 lb and would not likely be sufficient for a taste test. A few might be sacrificed and made into hors d'oeuvres, if necessary. However, if the project continues, these fish will be extremely important as potential brood stock, especially since we have two defined strains and 8 months worth of growth. If the project were not to continue with MP support, then I would suggest that these fish be tagged and stocked into suitable systems, so that their growth and survival could be monitored in the wild. It should be remembered that a certain portion of these fish are to be returned to the Leech Lake Reservation, if requested. Also, Rep. Munger would like to bring his fellow LCMR committee members through the ARF facility while it is still active and has walleye in it. I am trying to arrange a time after the current legislative session for this visit and will keep you informed so MP representatives can be present.

Observed and Predicted Walleye Growth at ARF

Date	Leech Lake 6/7	Leech Lake 7/7	Erskine 6/7	Erskine 7/7	Ambient
Nov 17	16.8	16.8	12.3	12.3	11.1
Dec 17	24.3	25.4	17.7	18.5	11.1
Jan 17	34.4	38.0	25.0	27.0	11.1
Feb 17	46.9	51.9	34.0	37.7	11.1
Mar 17	60.8	68.9	44.0	49.8	11.1
Apr 17	78.3	90.4	56.5	65.2	11.1
May 17	98.0	114.9	70.5	82.7	11.1

Table 1. Predicted walleye sizes from the bioenergetic model for both the Leech Lake and Erskine strains fed on 6 and 7 days a week. Also, walleye growth at ambient winter water temperature is shown.

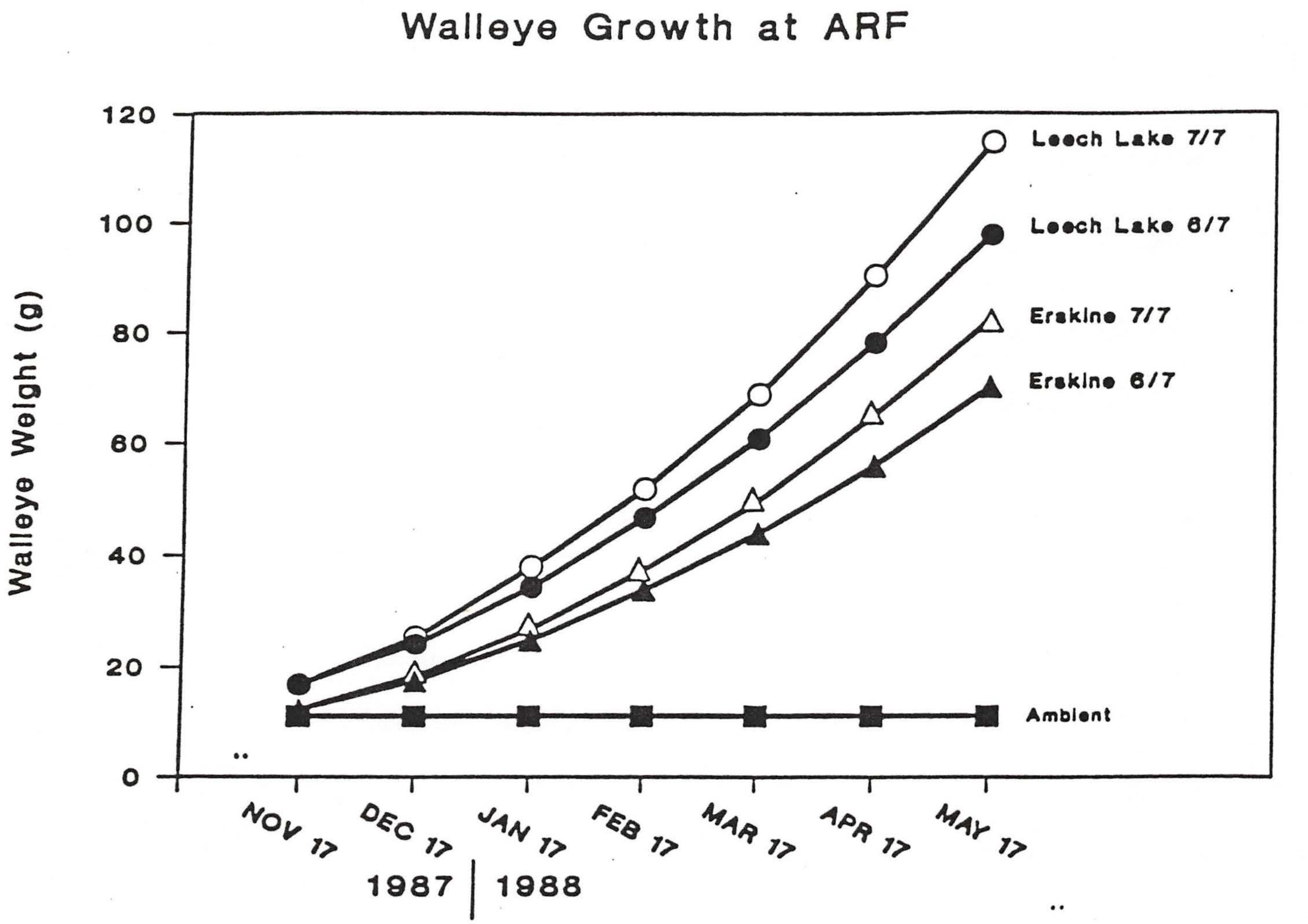

Figure 1. Observed (Observed G) and predicted size of walleyes in ARF starting on November 4, 1987 (Day 1). Predicted walleye sizes are from the bioenergetic model using ambient winter water temperature (Ambient G), current ARF conditions (ARF Predicted G), and at current ARF conditions, but fed 7 days/week (7/7 predicted G). (Observed growth in ARF lies on the predicted 6/7 lines).

Development of Thermally-Enhanced Walleye Aquaculture

Monthly Report for April 1988

Principal Investigator: Michael McDonald, Ph.D.

We had 3 walleye mortalities during the month of April. A single mortality from the Leech Lake (LL) strain and two from the Erskine (E) strain (however, one of these mortalities was due to the fish jumping out of the tank). We have a total of 2460 fish currently in the facility, 815 Leech Lake strain and 1655 Erskine strain walleye. The model predicted one mortality for the Leech Lake strain walleye and six for the Erskine strain. This is the second mortality estimate for each strain. It is still too early to tell about the general prediction accuracy of the model, but the results are promising (LL - 0% error, E - 0.2% over-estimate of entire population mortality).

Leech Lake walleye fingerlings at ARF weighed an average of 77.81 g on April 20, 1988. This is a 15.8 g increase in one month (25% increase in body weight). The walleye model predicted an average weight of 78.3 g; this is 0.6% over-estimate by the model. Erskine strain walleye had an average weight of 55.34 g. This is a 26% increase in body weight in one month, but this level of increase is not unexpected for the Erskine fish, since they are smaller. The model predicted an average weight of 56.5 g. This is a 2% over-estimate of growth by the model. Growth predictions for each month through May 17 are shown in Fig. 1 and in Table 1. The model is currently predicting walleye growth at ARF very well. However, growth in the lower tanks in the series seem to be less, likely due to the decrease in water quality in the second tank in the series. No Leech Lake fishes have been in a lower tank, while half of the Erskine strain fishes have been in the lower tanks. This may account for some of the deviation seen in the predictions by the model of the Erskine walleye.

Erskine walleye have been shifted exclusively to a 1/8" pellet diet. The Leech Lake walleye (switched last month) continue to be fed the 1/8" W-16 diet pellets. All fish are currently being fed at 3% body weight/d. Temperature was maintained at approximately 69^{o} F during April. Despite temperature and water level fluctuations at the end of March, because of low electrical demand at night and on weekends, the walleye in the facility were able to grow well. The ARF staff should be commended for their response to this problem and for the extra care that was given to the fish, while the problem was being ameliorated.

Walleye fingerlings from Leech Lake have a predicted 1:3.7 feed to fish conversion ratio. Actual feeding levels are higher due to the necessity of having sufficient feed in the system to assure sufficient feed consumption during the experiment. The model predicted a conversion of 1:4.2 for the Erskine fish. Recent comparative simulation of the walleye in the St. Louis River suggests that their conversion is on the order of 1:5.6.

Also, growth predictions of the St.Louis walleye suggest that it would require >2 times as long for these fish to achieve the same size as the Erskine strain or the Leech Lake strain growing in ARF.

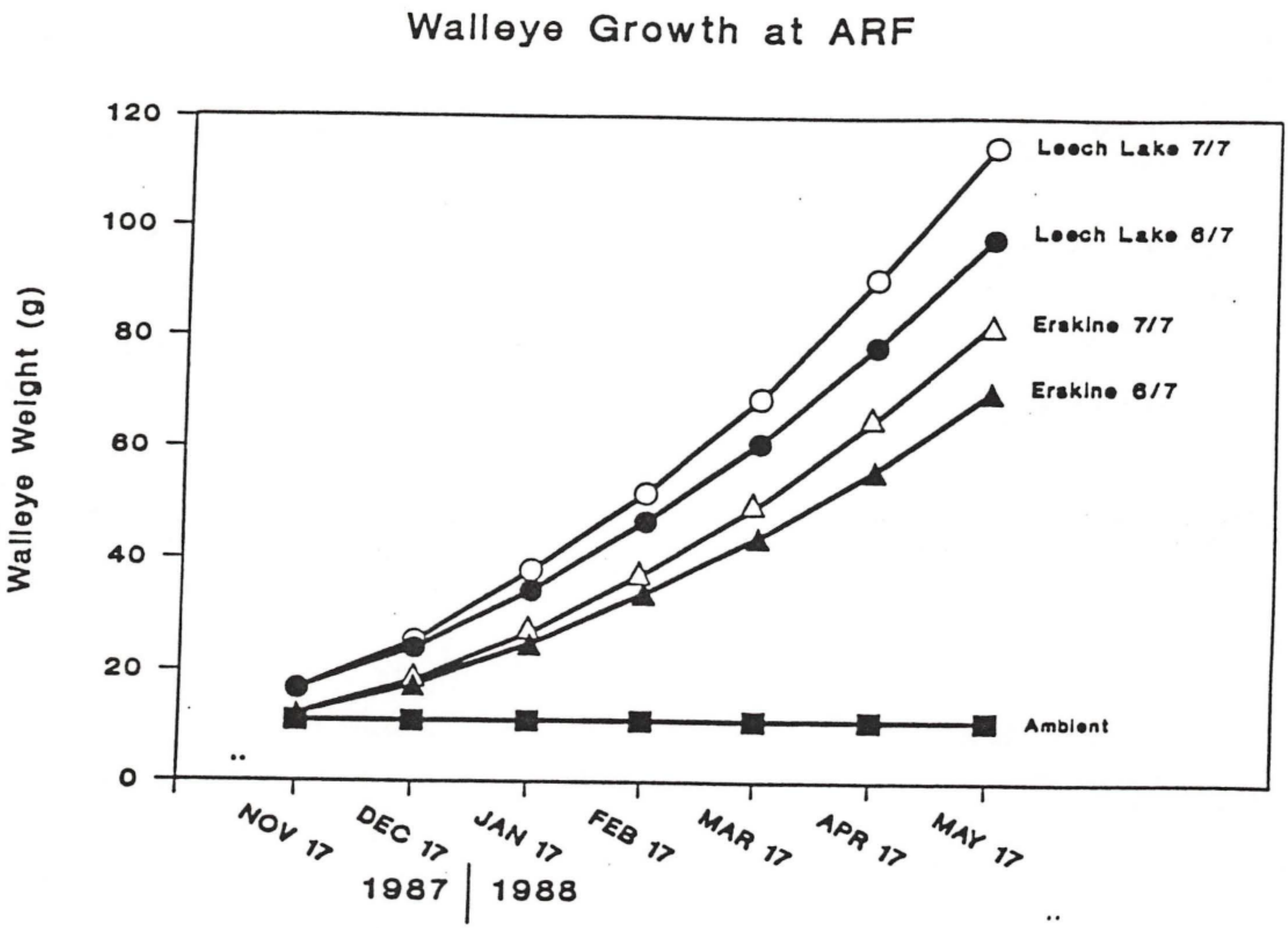

Figure 1. Observed (Observed G) and predicted size of walleyes in ARF starting on November 4, 1987 (Day 1). Predicted walleye sizes are from the bioenergetic model using ambient winter water temperature (Ambient G), current ARF conditions (ARF Predicted G), and at current ARF conditions, but fed 7 days/week (7/7 predicted G). (Observed growth in ARF lies on the predicted 6/7 lines).

Observed and Predicted Walleye Growth at ARF

Date	Leech Lake		Erskine		Ambient
	6/7	7/7	6/7	7/7	
Nov 17	16.8	16.8	12.3	12.3	11.1
Dec 17	24.3	25.4	17.7	18.5	11.1
Jan 17	34.4	38.0	25.0	27.0	11.1
Feb 17	46.9	51.9	34.0	37.7	11.1
Mar 17	60.8	68.9	44.0	49.8	11.1
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May 17	98.0	114.9	70.5	82.7	11.1

Table 1. Predicted walleye sizes from the bioenergetic model for both the Leech Lake and Erskine strains fed on 6 and 7 days a week. Also, walleye growth at ambient winter water temperature is shown.

Appendix B

Marketing and Culturing Walleye in Minnesota:
A Progress Report and Proposal

MARKETING AND CULTURING WALLEYE IN MINNESOTA: A PROGRESS REPORT AND PROPOSAL

Prepared by:
James A Skurla
Thomas Van Hale

Natural Resources Research Institute
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March 1988

[1]The Center for Economic Development is a joint program of the UMD School of Business and Economics and the UMD Natural Resources Research Institute.
[2]The Center for Water and Environment is one of three Centers within the Natural Resources Research Institute.

CENTER FOR ECONOMIC DEVELOPMENT

UNIVERSITY OF MINNESOTA, DULUTH

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EXECUTIVE SUMMARY

Based on our report entitled, "The Feasibility for Marketing and Culturing Walleyes in Minnesota," continued assessment of the options for the profitability, marketing and culture of walleye has been done. In the first report it was established that 90 percent of the walleye for human consumption are imported from Canada. Currently, Minnesota commercial walleye are extensively produced, but the profit margins are questionable. Experimental research suggests that intensive walleye culturing with warm water may improve the profit potential.

To estimate business profitability, three operating scenarios were investigated based on the facility design from the Caufield and Associates study. Business 1 purchases fingerlings to be sold as table walleye, and has a negative cash flow of-$77,982. Business 2 is identical to Business 1; however, it maximizes the facilities carrying capacity and sells fingerlings each month. It virtually broke even by showing a positive operating cash flow of $21,803. Finally, Business 3 has an operating cash flow of $276,703 by purchasing eggs, rather than fingerlings, and maximizing monthly revenue and carrying capacity. However, Business 3 also requires some advances in the culture of walleye.

Market research indicates that the demand for table walleye remains strong, but current supply is down, so prices have increased. A Minnesota Stocking Survey shows that the large markets for fingerlings are outside Minnesota. Minnesota clubs,

organizations and lake associations purchases are relatively small and would not currently support an aquaculture operation. Operation Walleye, Inc., is a not-for-profit extensive operation and claims profits as a pilot project. Walleye growers have mentioned they have sales in other states, including a $500,000 fingerling request from Colorado.

In September 1987 the biological growout at the Boswell Aquaculture Research Facility (ARF) began with 6500 fish from Golden Pond at Erskine, Minnesota and 1500 fingerlings from Leech Lake. Despite technical problems, growout results have been good with 33 percent of the wild fish still surviving and converted to artificial diets, as of February 1988. One of our objectives, converting wild caught walleye fingerlings to an artificial diet has recently been documented at ARF. It appears that the Leech Lake fingerlings are growing at a slightly faster rate than the Erskine fish. The bioenergetics models predict that growth would have been even greater if the fish were on a 7 day feeding cycle rather than a 6 day feeding cycle.

Future research should focus on the stocking market and growout and should address five major questions or issues. They are:

- Can eggs be obtained from a reliable source of eggs or is it more profitable to raise and hold brood stock?
- Can the fry hatched from eggs be grown to fingerlings at low cost?
- Will the fingerlings survive the intensive loading

stress and grow at predictable rates?

- Can the fingerlings be sold at monthly or regular intervals as necessary?
- What is the true value or price of the intensively grown, artificially fed walleye?

The proposed business research will develop a business plan that focuses on profitability by enhancing revenues and operating cost reductions and also market development outside Minnesota. The biological research will center on brood stock development, development of fry and fingerling feeds and the documentation of enhanced market value of intensively reared walleye.

INTRODUCTION

The purpose of this report and proposal is to continue to assess the profitability, markets, and culture of walleye in Minnesota. This research builds on the conclusions from "The Feasibility for Marketing and Culturing Walleye in Minnesota," by James Skurla and Thomas Van Hale, NRRI Business Group. It incorporates the information and knowledge that also has been gained from the current Minnesota Power funded project, "Development of Thermally-Enhanced Walleye Aquaculture," with Michael McDonald, NRRI Center for Water and the Environment, as Principal Investigator.

The report and proposal focuses on the integration of business and biological research with the objective of using the Clay Boswell Aquaculture Research Facility (ARF) as a prototype for a profitable operation. This report is divided into three parts.

1. Background - what the walleye research has been done.
2. Our Current Research Activities
3. Future Research Activities - necessary for insured profitability.

The final section of the report includes appendices and supporting information. Following the report is a more specific proposal of business and biological activities.

BACKGROUND

Since 1984, Minnesota Power has been using the thermal and water resources of the Clay Boswell electric generating plant for intensive aquaculture rearing. A number of species have been successfully reared in the Aquaculture Research Facility (ARF). The projects included catfish, rainbow trout, Atlantic salmon (Minnesota Power and the Minnesota Department of Natural Resources), and whitefish (Minnesota Power and Leech Lake Indian Reservation).

Moderate returns on investment for Atlantic Salmon, catfish, and whitefish could be obtained from full scale operations with these species.[1] However, current and future market conditions increase the risk of investment in these species. Worldwide development of intensive and extensive cultured Atlantic Salmon may saturate the market by the 1990's. Southern U.S. catfish farmers are currently struggling to maintain catfish prices above 60 cents a pound and hold their profit margins.[2] Whitefish is primarily a specialty market with high quality standards set by the Jewish community in urban markets, such as Chicago and New York.[3]

In May 1987, Minnesota Power and the NRRI Business Group discussed the need to determine the market potential for

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[1]Paul Johnson, Minnesota Power, personal communication.

[2]Catfish Journal, December, 1987.

[3]John Ringle, Leech Lake Reservation, personal communication.

commercial walleye production in Minnesota. Subsequently, the NRRI Business Group agreed to establish the feasibility of a Minnesota based walleye culture business, assessing current cultural practices and determining the value of using warm water in such an operation. To establish an economic baseline, the walleye market and cultural requirements for walleye were examined. The report entitled, "The Feasibility for Marketing and Culturing Walleye in Minnesota," was completed in August 1987.[4] The report's major findings are summarized below.

Walleye Markets

Two distinct markets were identified for walleye, 1) raising them for stocking in private and public waters, 2) table fish. Market data for walleye stocking was obtained from the Minnesota Department of Natural Resources (MDNR) and the walleye producers. Each contact provided information about the price and markets for various size walleye, and their concern about walleye culture. Stocking walleye are sold at three life cycle stages: eggs, fry, and fingerlings. Historical production of stocking-size walleye in Minnesota has been limited to a small number of producers because MDNR has controlled the in-state stocking program. Current walleye producers indicate the majority of current production is sold out of state. The exact size fry and fingerling market was not determined because the producers were

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4James A. Skurla and Thomas Van Hale, "The Feasibility for Marketing and Culturing Walleyes in Minnesota," NRRI Business Group, SBE/NRRI Center for Economic Development, August 1987.

reluctant to share market information. The producers did say the demand for eggs has exceeded the supply. This may change as 1987 legislation requires the MDNR make 2% of their annual walleye egg harvest available for sale at fair market prices. However, increasing demand may offset the increased supply.

A Canadian walleye marketer, a Chicago fish broker, and several Minnesota wholesalers and retailers of walleye provided the market and price information for table market walleye.[5] The consumption of fresh and frozen fish in the U.S. is at an all time high. Fish brokers state there is no problem finding buyers for walleye fillets. Ninety percent of U.S. walleye consumption is imported from Canada, primarily through Canada's Freshwater Fish Marketing Corporation. Walleye prices are quoted daily, varying by season, amount of processing, and availability. Table 1 shows current price ranges for the various size walleye.

TABLE 1
1987 Walleye Price

Markets	Price Ranges
Eggs for Hatcheries	\$400 to \$1000 per quart
Fry for Stocking	\$16.00 to \$25.00 per 1000
2" Fingerling - Stocking	\$0.15 to \$0.25 each
Wholesale - Round Weight[1]	\$1.25 to \$3.00 per pound
Retail - Processed Fillet	\$3.25 to \$6.00 per pound

[1]Round weight is the weight of the fish right from the water

[5]Ron Hart, Morey's Fish House, Motley, Minnesota; Brian McDuffy, A. Kemp's Fisheries, Duluth, Minnesota; Bob Rubin, Chicago Fish House, Chicago, Illinois, personal communication.

without any processing.

Walleye Culture

The feasibility of intensively culturing walleye was determined by a literature review and by interviewing walleye growers and biologists. We focused our efforts toward finding the type of walleye operation that would provide the highest survival rate and generate the greatest revenue.

We found little operational information about intensive walleye culture (i.e. where variables such as diet, temperature, parental stocks, and water characteristics were controlled). Most of the information from the literature and growers dealt with extensive walleye culture. In an extensive system few or no environmental variables are controlled. Walleye raised in natural and man-made ponds are dependent upon natural oxygen concentrations and temperatures. Walleye growth stops for at least six months in the winter and some rearing lakes winter kill due to a lack of oxygen. Also, the naturally available food is sometimes supplemented with minnows (an additional cost). One grower, Golden Pond at Erskine, Minnesota, does aerate his ponds to maintain suitable oxygen levels.

Walleye can be grown in Minnesota based on an integrated, extensive process. Brood stock should be maintained to assure a source of eggs The following are currently recommended for a self-sufficient operation:

- A hatchery for egg incubation and fry production

- Drainable outdoor growout ponds for fry stocking
- Supplemental aeration
- Supplemental feeding

Although walleye can be produced by this method, slow growth rates (due to the short growing season) and uncertain survival rates makes profitability of such an operation questionable. Table 2 gives the ranges of survival rates for different size walleye.

TABLE 2
Walleye Survival Rates

From	To	Survival Rates
Eggs[1]	Fry	55 - 70%
Fry	3" Fingerlings	0 - 50%
3" Fingerlings	6" Fingerlings	0 - 70%
6" Fingerlings	Table Size Fish	0 - 90%

[1]Based on hatchery experience

Even though some of the survival rates are results of experimental research, the growers we contacted have also experienced varied survival rates. Golden Pond reported survival rates of 0 to 50% for different ponds in the same growing year.[6] Experimental research indicates that, once the walleye are past the fry stage, controlling more variables increases the survival

[6]Leonard Rydell, Golden Pond, Erskine, Minnesota, personal communication.

rate,[7] suggesting that an intensive walleye operation might result in both higher and more consistent survival rates. Improving the level and constancy of walleye survival through intensive culture may also increase the profit potential for a walleye culture business by reducing production uncertainty and increasing the number of walleye available for sale.

An intensive walleye operation incorporating heated water may further increase the profit potential. Research indicates warm water speeds up the growth process which may allow the fish to be marketed sooner.[8] Alternatively, larger fish raised in warm water could be marketed at the same time as smaller fish raised in unheated water, and likely command higher prices. Although the customer may be willing to pay a higher price, if the fingerlings are larger or if they are available sooner, this must be correlated with increased survival after stocking. Based on Minnesota Power's past experience in raising fish intensively in warm water, fish raised in heated water weighed more than similar size fish raised in unheated water. To maximize revenues these fish should have to be sold by the pound rather than by the inch as is the common practice. Whether or not the customer would be willing to purchase fingerlings by the pound would have

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[7]John G. Nickum, "Walleye," in Culture of Nonsalmonoid Freshwater Fishes, ed. John Stickney, (Boca Raton, Florida:CRC Press 1986.

[8]H.T. Huh, H.E. Calbert and D.A. Stuider, "Effects of Temperatures and Light on Growth of Yellow Perch and Walleye Using Formulated Feeds," Transactions of the American Fisheries Society, Vol. 105, No. 2, 1976.

to be answered.

Another option open to an intense warm water walleye operation is marketing table size fish. The walleye growers we contacted stated that it is uneconomical to grow walleye to table size. Increased growth in warm water may improve the economy of growing walleye for the table market. In addition, walleye could be grown to a consistent size. This may result in higher prices when marketed to consumers concerned about portion control, such as restaurants or frozen dinners.

Each of the possibilities mentioned for increasing the profit potential represents an advance in walleye culture. One way to answer the questions raised by these possibilities is to intensively culture walleye in warm water, under research conditions. Operational and cultural data from such a research project could establish survival rates, growth rates, and production costs related to size, all of which are necessary to determine the ultimate profitability of commercial walleye production.

CURRENT RESEARCH ACTIVITIES

Business Profitability

Several operating scenarios were investigated to determine the profitability of a warm water intensive walleye operation. The facility used for these evaluations was based on the one proposed in the feasibility study done by Caufield and Associates for MDNR and Minnesota Power. Only the direct operating costs before depreciation, taxes, and debt service were used for these comparisons.

The marketing information available indicates a market exists for table size walleye if they can be grown economically; therefore, all three scenarios explored growing walleye to table size. Each of the three business operations are explained below with the results listed in the Table 3. The annual operating statements and feed requirements are in Appendix A.

TABLE 3

	Business 1	Business 2	Business 3
SALES			
Stocking		280750	405705
Table	100646	99957	99957
Total Sales	100646	380707	505707
Cost of Sales			
Fingerlings	16500	165000	
Feed	18128	49904	64004
Eggs			21000
Total Cost of Sales	34628	214904	85004
Operating Costs	144000	144000	144000
Profit Before Deprec, Taxes, & Debt Service	-77982	21803	276703

Business 1

This walleye business would buy fingerlings (already converted to artificial diets) from outside suppliers in late August and raise them on an artificial diet to table size. The number of fingerlings purchased is determined by the carrying capacity of the facility (approximately 50,000 pounds) and the estimated growth and survival rates. Using these variables it was determined that 55,000 fingerlings would be bought, resulting in 50,323 pounds of walleye available for sale at the end of the 9 month growout period.

This business results in a loss of $77,982. One way to improve this operation would be to use the facility during the three months it would sit empty. Catfish were considered for growout, but they could not generate enough income to reduce the loss to zero. Other species may offer higher profit margins, however, their inclusion in the analysis was not attempted.

It was apparent from Business 1 that more sales would have to be generated by the facility in order to make a profit. This led to considering Business 2.

Business 2

Business 2 is identical to Business 1 except it maximizes the facility's carrying capacity by starting with a large number of fingerlings and selling off the excess at the end of each month. The beginning stock of 550,000 fingerlings would reach the maximum carrying capacity of the facility in 60 days. At that time a number of fingerlings would be sold for stocking purposes. This number would be just enough to allow the remaining stock to again reach the facility's capacity in 30 days when another group would be sold for stocking. This 30 day cycle of grow and sell would continue until the walleye were table size.

A business operated in this manner would have sales of $380,707 and a profit of $21,803 at year end. Even though this is $99,785 better than Business 1 it still does not allow much for debt service, taxes, and depreciation. Improving these results would take an increase in sales, decrease in costs, or both. The two largest expense categories for Business 2 are fingerlings, 43% of sales, and operating costs, 38% of sales. It is unlikely that the operating costs could be reduced significantly. However, the fingerling cost could be reduced if the business hatched eggs and raised their own fingerlings.

Business 3

Business 3 expands the operation of Business 2 by purchasing and hatching eggs, then raising its own fingerlings from the fry instead of buying them. The facility as proposed in the Caufield report has a 30 jar hatchery which would hold 30 quarts of eggs. Using survival rates for the egg hatch and fry growout to fingerlings of 70% and 50% respectively, the 30 quarts of eggs would result in 550,000 fingerlings available for growout to table and 500,000 for sale. This operation results in Business 3 having both increased sales and decreased costs as compared to Business 2 and an operating profit of $276,703.

Even though the profit potential of Business 3 is high, there are a number of questions that must be answered before the profits can be predicted with any degree of certainty.

Market Research

The market Feasibility Study (Skurla and Van Hale) indicated a strong demand for walleye fillets by restaurants and households. Consumer demand remains high, but available Canadian supply in 1988 is less than in 1987. As a result, walleye prices have increased by about one dollar in 1988 or are at the upper limits as shown on page 3. Round prices are currently about $3.00 per pound and fresh or frozen fillets are running between $6.00 and $7.00. Unless the Canadian catch rises dramatically, prices will remain high during the year.[9]

The walleye stocking market includes walleye eggs for hatcheries, fry, and two inch fingerlings to meet the needs of stocking for the sport fishing demand for walleye. MDNR controls stocking lakes in Minnesota, but does receive assistance from sports clubs, organizations and lake associations. These groups can stock private lakes that do not have public access.

Minnesota Stocking Survey

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[9]Bob Rubin, Chicago Fish House, Chicago, Illinois, personal communication.

A Minnesota Stocking Survey was conducted in November 1987 to determine the quantity and size of fish purchased by clubs, organizations, and lake associations. The survey also shows where, and from whom, the groups purchased their fish, where the fingerlings were stocked, and if the group was interested in purchasing fish from alternative sources. The survey was mailed to 301 groups throughout the State and 12 percent responded to the request. Based on the sample respondents it is estimated that clubs, organizations, and lake associations are generally small and not well funded. In addition, from written comments many groups are active participants with the MDNR in the State stocking programs in which the MDNR provides its own fingerlings. Because of these two factors, a private Minnesota aquaculture operation will have to rely on customers outside Minnesota to market their fingerlings, at least for the present.

Operation Walleye, Inc.

As a result of the Minnesota Stocking Survey, contact was made with Operation Walleye, Inc. in Alexandria, Minnesota.[10] This not-for-profit enterprise was established in 1984 as a five year project with funding from MDNR, Legislative Commission on Minnesota Resources (LCMR), fraternal organizations, and memberships in Operation Walleye. The major objective of the project was to develop dependable data to be applied to walleye fingerling production in Minnesota.

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[10]Cal Courmeya, Operation Walleye Inc., Alexandria, Minnesota, personal communication.

Another objective was to stock the raised fingerlings back into Alexandria area lakes to potentially increase walleye sport fish populations. Therefore, the fish are not sold on the open market, but sold to MDNR, who stock them in the public waters. As a general rule, the MDNR prefers to raise and stock their own fish, but agreed to this program because it was maintained by, and benefited, the Alexandria region.

To determine economic viability for farmers of extensive pond walleye culturing, Operation Walleye, has collected pond operation costs data. These costs include actual out-of-pocket expenses, equipment amortized over five years, and labor charged at $8.00 per hour.

Through the first four years, 2,979 acres of water has produced 1,809,879 fingerlings weighing 60,329 pounds. This production has a net cost per fish of 20.1 cents.[11] If the current market price is 20 cents per inch, then a 6 inch fingerling is worth $1.20. The profit before taxes is 99.1 cents per fish. Operation Walleye, acknowledges these statistics are averages of all production, and admits the risks involved. Some of the ponds have been successful, while others have been failures. So, the data shows that not all aquaculture operations will be profitable.

<u>Outstate Markets</u>

Locating customers outside Minnesota continues to be a

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[11] <u>THE FIRING LINE</u>, December, 1987, p. 11, Operation Walleye Newsletter.

concern for the aquaculture enterprises. Surveyed growers generally will not discuss specific customers. However, Robert Olson, President of the Minnesota Fish Farmers' Association, stated publicly that he received a Colorado inquiry (which he could not fill) for 500,000 six inch walleye fingerlings at $1.00 each.[12]

Besides Colorado, other states that have been mentioned by growers include Iowa, North and South Dakota, Nebraska, Missouri, and Tennessee. Another concern of growers is having a large enough customer list, because the time when the fish are ready for market does not always coincide with buyers' schedules.

ARF Growout Research

Based on the conclusions of The Market Feasibility Study (Skurla and Van Hale), Minnesota Power funded the feasibility and assessment of thermally-enhanced, intensive walleye culturing at ARF. Michael McDonald of the NRRI Center for Water and the Environment, in collaboration with Minnesota Power staff, is assessing the potential for growth, survival, and food conversion of walleye fingerlings under optimal conditions at ARF. Included as part of the research is the bioenergetics modeling which will predicts future growth of walleye based on current conditions. This effort will establish the initial feasibility for walleye production at ARF. Growth rates, survival, and food conversion

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[12]Minnesota Aquaculture Advisory Committee, January 29, 1988 meeting, St. Paul, Minnesota.

efficiency found during the project are being compared to the estimates from the walleye bioenergetics model, and the model is being revised for more efficient prediction capabilities.

The ARF facility became operational during September 1987 with the delivery of 6500 four inch fingerlings from Golden Pond and 1500 additional fingerlings delivered during October from Leech Lake Indian Reservation. In order to maintain strain integrity, these two groups have been held separately. However, the model and the data collected had been pooled from September through December 1987. Beginning in February 1988 the results for each strain will be presented separately.

One of the project's major objectives was to determine if large wild caught walleye fingerlings could be converted to artificial food diets. This has been recently documented for walleye in ARF.[13] The six day feeding cycle began by feeding the walleye 5% of their body weight and as the walleye became accustomed to dry food and have increased in size, the ration was reduced to 3% of body weight to provide better estimates of actual food consumption.

An overall survival rate of 33% (as of February 1988) is good when considering the three problems that have been overcome. First was the conversion of the wild walleye to artificial dry diets. Then, large scale fungal infection occurred shortly after stocking. After application of U.S.D.A approved antibiotics

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[13]Michael McDonald, "Development of Thermally-Enhanced Walleye Aquaculture, Monthly Reports."

(tetracycline), the infection was controlled. Also, on October 16, 1987, the single operating power generation unit (Unit 3) was shut down. This caused the water temperature to drop from a normal 68° F to the river temperature of 42° F in the facility. However, ARF staff were able to slowly re-acclimate the fish when Unit 3 was started on October 17, 1987. The resulting short-term stress mortality was minimized by quick action of the ARF staff. However, this occurred at a critical point in the acclimation of the walleye to the artificial dry diet. This may have decreased initial growth and increased long term mortality.

The growth rates in grams are shown in Figure 1 below. Four different rates are included to show natural growth in the wild, bioenergetics model predicted growth of Leech Lake and Erskine fish based on feeding a 6 out of 7 day feeding cycle (current operation), and 7 out of 7 day feeding cycle for Leech and Erskine walleye. The fingerlings started at 11.1 grams in September 1987 currently (February 1988) weigh an average 38.3 grams. This compares to an estimated 7 day feeding of 42.2 grams.

Because of the differential starting weights for Erskine and Leech Lake stocks, each stock has been modeled separately. Current mean size of Leech Lake fish is 46.9 grams while the mean size of Erskine fish is 34.0 grams. By using the bioenergetics model to adjust for initial differences, it appears that the Erskine walleye may still have a slightly slower growth rate (about 5%) than the Leech Lake walleye.

FIGURE 1

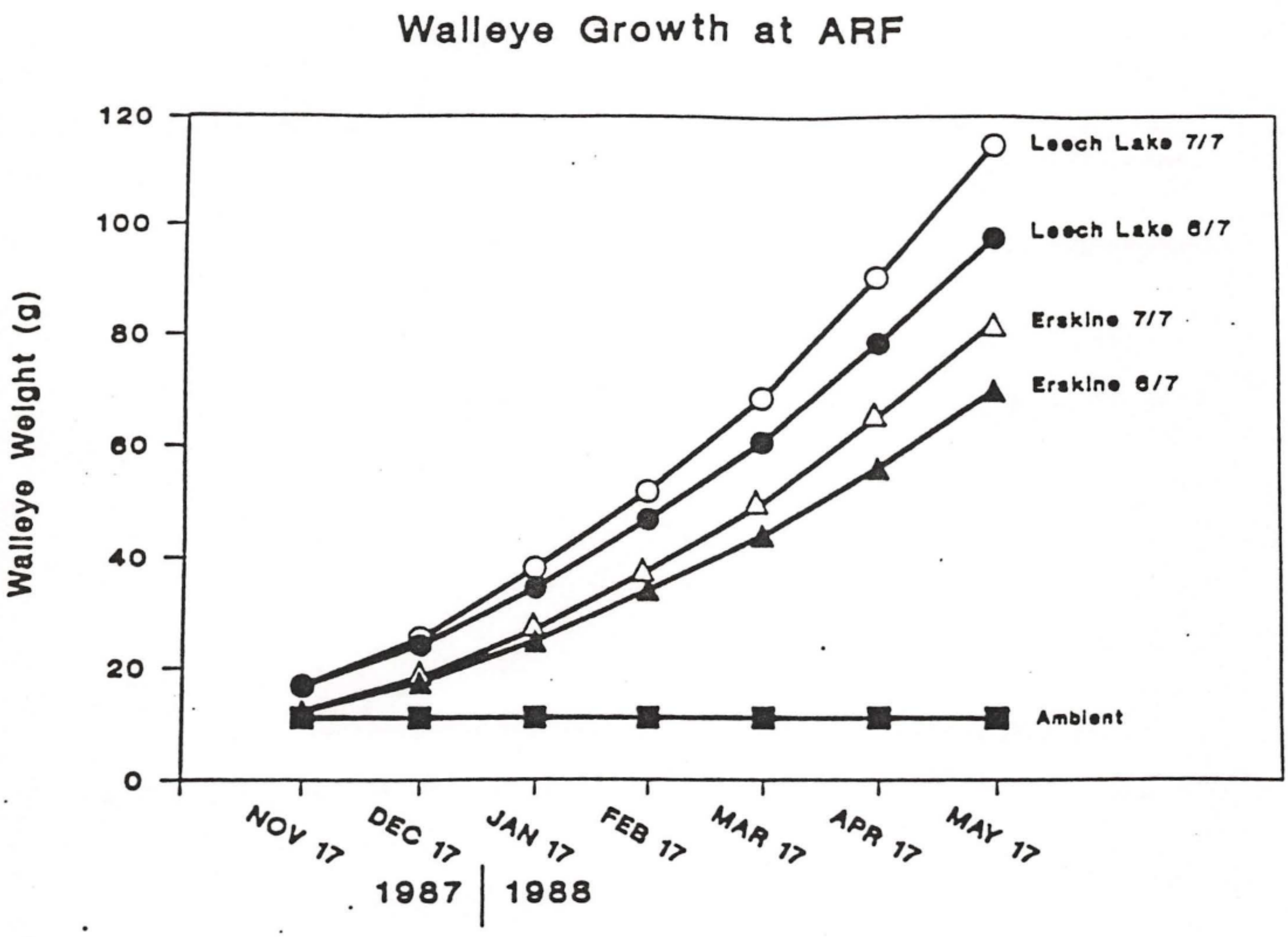

Fig. 1. Predicted growth for ARF walleye strains when fed 6 out of 7 days and when fed 7 out of 7 days. Actual Leech Lake and Erskine 6/7 growth through February 17 fall on predicted lines. Even after adjusting for different initial starting sizes, the Leech Lake strain shows faster growth.

FUTURE RESEARCH ACTIVITIES

The key to any aquaculture operation is to develop the business plan that obtains cash flow as quickly as possible. Since warm water significantly increases the walleye growth over extensively cultured fish, ARF has a comparative advantage. This advantage must be fully utilized to offset the potentially higher production costs of intensive culturing. The business development of the ARF facility depends on reliability of egg sources, reducing operating costs, increasing growth rates and survival, improving artificial feed conversion and market development.

In order to be profitable, the business should have access to eggs, and sell fry and fingerlings. The table market should not be considered unless there is a substantial jump in prices to offset the risk of holding, otherwise salable fish, for nearly an additional year. Also, if stock improvements and growth rates are enhanced, the table market should be re-evaluated. However, there are five questions or issues that must be addressed to reach profitability. They are:

- Can the eggs be obtained from a reliable source or is it more profitable to raise and maintain brood stock as a source of eggs?
- Can the fry hatched from the eggs be grown intensively to fingerlings at low cost?
- Will the fingerlings survive the intensive loading stress and maintain growth at predictable rates?
- Can the fingerlings be sold at monthly or regular

intervals in the necessary quantities?

- What is the true value or market price of the intensively grown, artificially fed walleye?

To address these questions both economic and biological research is required. A strategy that will likely increase profits will require the raising and holding of brood stock that have been artificially fed and selected for rapid growth. Any extra egg production that is not needed for the facility would be sold generate early revenue. However, additional facilities and improvement of the pond on the site would be necessary.

The biological research should focus on brood stock development and the assessment of different walleye strains for egg production and fry and fingerling production. Continued development of the bioenergetics models, especially for fry, will be necessary for improving predictability of production under various growth conditions. Testing and development of fry and fingerling foods for increasing the food conversion ratio will reduce food and operating costs. Finally, the use of other species for possible polycultures should be examined to optimize food utilization and enhance profitability.

Once the biological analysis estimates the timetable and quantity of a particular size fish that can be raised, optimum load capacity and withdrawals will be determined. The objective is to maximize profits, not revenue; therefore, a complete business analysis of production, marketing, and transportation costs based on the updated information is necessary. Some potential states or customers may be excluded because of high transportation costs, or sales volumes may be insufficient to be highly profitable.

The two other economic and marketing questions that are raised should also be addressed to determine the actual markets and prices for ARF raised walleye. The first question is whether it's better to bring small fish to market sooner than the competition (extensively raised), or bring larger fingerlings to market at the same time as extensively raised fish.

The biological research will determine if it can be physically done. But outstate walleye buyers may be skeptical about the early market delivery of ARF raised fish. The market and buying schedules are currently set because of the availability of extensively grown fish. Buyers may have to be educated to change past practices. Delivery of larger fingerlings at the beginning of spring would allow the walleye to grow for the entire summer rather than the current practice of stocking in late fall. With current practice, walleye growth stops shortly after stocking because of winter temperatures.

The prices that different states are willing to pay needs to be documented. Since few or no walleye are marketed before the end of the extensive growing season, early market ARF fish should be very valuable. However, this price is unknown and must be established. In addition, determining the extra value that a larger ARF fingerling has, as compared to extensively grown fish when brought to market at the same time is very important. Only by establishing the prices or values can it be resolved whether it's more profitable to deliver earlier or at the same time as the competition. The second question that should be examined is whether artificially fed fish are more valuable than naturally or minnow raised ones. Rathbun Hatchery in Iowa has found artificially fed fingerlings are extremely valuable because they have perhaps a 16 times greater survival rate when stocked out.[14] These claims need to be verified. As a marketing tool, it is also important to document the value of ARF walleye. These fish may be marketed as a higher quality product because of their greater survival and faster growth, and thus command a higher price.

[14] Larry Mitzner, Rathbun Hatchery, Iowa DNR, presentation at the Coolwater Fisheries Workshop, Aberdeen, South Dakota, January 5, 1988.

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APPENDIX A

TABLE 1

BUSINESS 1
FINGERLING TO TABLE

DAY	WEIGHT IN GRAMS	POP. SIZE	TOTAL WEIGHT IN LBS	CUM. WEIGHT GAIN	WEIGHT GAIN/ 30 DAY PERIOD	FEED CONSUMED 30 DAYS IN LBS	COST OF FEED $.37/LB	AMOUNT SOLD	SELLING PRICE	SALES
1										
10										
20										
30										
40										
50										
60										
70										
80										
90										
100	10.9503	55000	1327	0	0		0			
110	14.6367	54108	1744	418	0		0			
120	19.1038	53230	2240	495	0		0			
130	24.4333	52366	2818	578	1492	2238	552			
140	30.7081	51517	3485	666	0		0			
150	38.011	50681	4243	759	0		0			
160	46.4257	49859	5099	855	2280	3420	844			
170	56.0359	49050	6054	956	0		0			
180	66.9255	48254	7113	1059	0		0			
190	79.1785	47471	8279	1166	3181	4771	1177			
200	92.879	46701	9554	1275	0		0			
210	108.1109	45944	10941	1386	0		0			
220	124.9582	45198	12440	1500	4161	6242	1540			
230	143.5045	44465	14055	1615	0		0			
240	163.8334	43744	15786	1731	0		0			
250	186.0281	43034	17633	1848	5193	7790	1921			
260	210.1715	42336	19599	1965	0		0			
270	236.3465	41649	21682	2083	0		0			
280	264.6351	40973	23883	2201	6250	9375	2312			
290	295.1195	40309	26202	2319	0		0			
300	327.8812	39655	28639	2437	0		0			
310	363.0012	39012	31192	2553	7309	10963	2704			
320	400.5604	38379	33861	2669	0		0			
330	440.6389	37756	36645	2784	0		0			
340	483.3166	37143	39542	2897	8350	12525	3089			
350	528.6728	36541	42551	3009	0		0			
360	576.7863	35948	45670	3119	0		0			
365	601.9015	35365	46836	1215	0		0			
370	656.6734	34791	50323	3437	10781	16172	3989	50323 LBS	2.00 /LB	100646
TOTAL					48996	73495	18129			100646

TABLE 2

Business 1
Fingerling to Table
Year 1 Cashflows before Taxes & Debt Service

Statement of Income & Expense

	AUG	SEP	OCT	NOV	DEC	JAN	FEB	MAR	APR	MAY	JUN	JUL	YTD Total
Income:													
Stocking size													
Table size										100646			1006
Total Sales	0	0	0	0	0	0	0	0	0	100646	0	0	1006
Cost of Sales													
Fingerlings	16500												165
Feed	0	552	844	1177	1540	1921	2312	2704	3089	3989			181
Freight													
Total COGS	16500	552	844	1177	1540	1921	2312	2704	3089	3989	0	0	346
Gross Margin	-16500	-552	-844	-1177	-1540	-1921	-2312	-2704	-3089	96657	0	0	6601
Expenses													
Labor	5250	5250	5250	5250	5250	5250	5250	5250	5250	5250	5250	5250	6300
Selling Expenses													
Telephone	167	167	167	167	167	167	167	167	167	167	167	167	200
Rent	33	33	33	33	33	33	33	33	33	33	33	33	40
Heat	2133	2133	2133	2133	2133	2133	2133	2133	2133	2133	2133	2133	2560
Electrical Service	2500	2500	2500	2500	2500	2500	2500	2500	2500	2500	2500	2500	3000
Travel & Vehicle	167	167	167	167	167	167	167	167	167	167	167	167	200
Maint. Tanks, Bldg, Ground	417	417	417	417	417	417	417	417	417	417	417	417	500
Chemicals, Nets, Boots, et	500	500	500	500	500	500	500	500	500	500	500	500	600
New Equip & Misc.	10000												1000
Total Operating Expenses	21167	11167	11167	11167	11167	11167	11167	11167	11167	11167	11167	11167	14400
Operating Profit	-37667	-11719	-12011	-12344	-12707	-13088	-13479	-13871	-14256	85490	-11167	-11167	-7798
Cashflow Bfore Debt Service	-37667	-11719	-12011	-12344	-12707	-13088	-13479	-13871	-14256	85490	-11167	-11167	
Cumulative Cashflow	-37667	-49385	-61396	-73740	-86446	-99534	-113013	-126883	-141139	-55649	-66815	-77982	

TABLE 3

BUSINESS 2
FINGERLING TO TABLE
MAXIMUM LOADING

DAY	WEIGHT IN GRAMS	POP. SIZE	TOTAL WEIGHT IN LBS	CUM. WEIGHT GAIN	WEIGHT GAIN/ 30 DAY PERIOD	FEED CONSUMED 30 DAYS IN LBS	COST OF FEED $.37/LB	AMOUNT SOLD	SELLING PRICE	SALES
1										
10										
20										
30										
40										
50										
60										
70										
80										
90										
100	10.9503	550000	13266	0	0		0			
110	14.6367	541077	17444	4178	0		0			
120	19.1038	532299	22399	4955	0		0			
130	24.4333	523664	28182	5784	14917	22375	5519			
140	30.7081	515169	34845	6663	0		0			
150	38.011	506811	42433	7587	0		0			
160	46.4257	498589	50985	8553	22803	34204	8437	195000 EA	0.50 EA	97500
170	56.0359	298664	36863	5818	0		0			
180	66.9255	293819	43313	6449	0		0			
190	79.1785	289052	50411	7099	19366	29050	7166	100000 EA	0.75 EA	75000
200	92.879	185985	38049	5078	0		0			
210	108.1109	182968	43570	5521	0		0			
220	124.9582	180000	49543	5973	16572	24858	6132	50000 EA	0.75 EA	37500
230	143.5045	127891	40425	4644	0		0			
240	163.8334	125816	45403	4978	0		0			
250	186.0281	123775	50717	5314	14936	22404	5526	33000 EA	0.75 EA	24750
260	210.1715	89302	41341	4146	0		0			
270	236.3465	87853	45735	4394	0		0			
280	264.6351	86428	50379	4643	13183	19775	4878	20000 EA	1.00 EA	20000
290	295.1195	65350	42481	3760	0		0			
300	327.8812	64290	46431	3950	0		0			
310	363.0012	63247	50570	4139	11849	17774	4384	14000 EA	1.00 EA	14000
320	400.5604	48448	42745	3369	0		0			
330	440.6389	47662	46260	3514	0		0			
340	483.3166	46889	49917	3657	10541	15811	3900	10000 EA	1.20 EA	12000
350	528.6728	36291	42260	2988	0		0			
360	576.7863	35702	45358	3098	0		0			
365	601.9015	35123	46565	1207	0		0			
370	656.6794	34553	49978	3414	10707	16061	3962	49978 LBS	2.00 /LB	99957
TOTAL					134875	202312	43904			380707

TABLE 4

Business 2
Fingerling to Table MAXIMUM LOADING
Year 1 Cashflows before Taxes & Debt Service

Statement of Income & Expense	AUG	SEP	OCT	NOV	DEC	JAN	FEB	MAR	APR	MAY	JUN	JUL	YTD Total
Income:													
Stocking size			97500	75000	37500	24750	20000	14000	12000				2807
Table size										99957			999
Total Sales	0	0	97500	75000	37500	24750	20000	14000	12000	99957	0	0	3807
Cost of Sales													
Fingerlings	165000												1650
Feed	0	5519	8437	7166	6132	5526	4878	4384	3900	3962			499
Freight													
Total COGS	165000	5519	8437	7166	6132	5526	4878	4384	3900	3962	0	0	2149
Gross Margin	-165000	-5519	89063	67834	31368	19224	15122	9616	8100	95995	0	0	1658
Expenses													
Labor	5250	5250	5250	5250	5250	5250	5250	5250	5250	5250	5250	5250	6300
Selling Expenses													
Telephone	167	167	167	167	167	167	167	167	167	167	167	167	200
Rent	33	33	33	33	33	33	33	33	33	33	33	33	40
Heat	2133	2133	2133	2133	2133	2133	2133	2133	2133	2133	2133	2133	2560
Electrical Service	2500	2500	2500	2500	2500	2500	2500	2500	2500	2500	2500	2500	3000
Travel & Vehicle	167	167	167	167	167	167	167	167	167	167	167	167	200
Maint. Tanks, Bldg. Ground	417	417	417	417	417	417	417	417	417	417	417	417	500
Chemicals, Nets, Boots, et	500	500	500	500	500	500	500	500	500	500	500	500	600
New Equip & Misc.	10000												1000
Total Operating Expenses	21167	11167	11167	11167	11167	11167	11167	11167	11167	11167	11167	11167	14400
Operating Profit	-186167	-16686	77896	56667	20201	8057	3955	-1551	-3067	84828	-11167	-11167	2180
Cashflow Bfore Debt Service	-186167	-16686	77896	56667	20201	8057	3955	-1551	-3067	84828	-11167	-11167	
Cumulative Cashflow	-186167	-202852	-124956	-68289	-48087	-40030	-36075	-37625	-40692	44136	32970	21803	

TABLE 5

BUSINESS 3
EGGS TO TABLE
MAXIMUM LOADING

DAY	WEIGHT IN GRAMS	POP. SIZE	TOTAL WEIGHT IN LBS	CUM. WEIGHT GAIN	WEIGHT GAIN/ 30 DAY PERIOD	FEED CONSUMED 30 DAYS IN LBS	COST OF FEED $.37/LB	AMOUNT SOLD	SELLING PRICE	SALES
1										
10	Purchase 30 quarts of eggs @ $700/qt = $21,000									
20	30 quarts (3,000,000 eggs) are hatched with 70% success rate = 2,100,000 fry									
30	2,100,000 fry are raised to fingerlings with 50% survival = 1,050,000 fingerlings									
40	500,000 fingerlings are sold @ $.25 each = $125,000									
50	550,000 are grown out with maximum loading of the facility									
60										
70										
80										
90								500000 EA	0.25 EA	125000
100	10.3503	550000	13266	0	0		0			
110	14.6367	541077	17444	4178	0		0			
120	19.1038	532299	22399	4955	0		0			
130	24.4333	523664	28182	5784	14917	22375	5519			
140	30.7081	515169	34845	6663	0		0			
150	38.011	506811	42433	7587	0		0			
160	46.4257	498589	50985	8553	22803	34204	8437	195000 EA	0.50 EA	97500
170	56.0359	298664	36863	5818	0		0			
180	66.9255	293819	43313	6449	0		0			
190	79.1785	289052	50411	7099	19366	29050	7166	100000 EA	0.75 EA	75000
200	92.879	185985	38049	5078	0		0			
210	108.1109	182963	43570	5521	0		0			
220	124.9582	180000	49543	5973	16572	24858	6132	50000 EA	0.75 EA	37500
230	143.5045	127891	40425	4644	0		0			
240	163.8334	125816	45403	4978	0		0			
250	186.0281	123775	50717	5314	14936	22404	5526	33000 EA	0.75 EA	24750
260	210.1715	89302	41341	4146	0		0			
270	236.3465	87853	45735	4394	0		0			
280	264.6351	86428	50379	4643	13183	19775	4878	20000 EA	1.00 EA	20000
290	295.1195	65350	42481	3760	0		0			
300	327.8812	64290	46431	3950	0		0			
310	363.0012	63247	50570	4139	11849	17774	4384	14000 EA	1.00 EA	14000
320	400.5604	48448	42745	3369	0		0			
330	440.6389	47662	46260	3514	0		0			
340	483.3166	46889	49917	3657	10541	15811	3900	10000 EA	1.20 EA	12000
350	528.6728	36291	42260	2988	0		0			
360	576.7863	35702	45358	3098	0		0			
365	601.9015	35123	46565	1207	0		0			
370	656.6734	34553	49978	3414	10707	16061	3362	49978 LBS	2.00 /LB	99957
TOTAL					134875	202312	43904			505707

TABLE 6

Business 3
Eggs to Table MAXIMUM LOADING
Yearly Cashflows before Taxes & Debt Service

Statement of Income & Expense

	AUG	SEP	OCT	NOV	DEC	JAN	FEB	MAR	APR	MAY	JUN	JUL	YTD Total
Income:													
Stocking size	125000		97500	75000	37500	24750	20000	14000	12000				40575
Table size										99957			9995
Total Sales	125000	0	97500	75000	37500	24750	20000	14000	12000	99957	0	0	50570
Cost of Sales													
Fingerlings													
Feed	9200	5519	8437	7166	6132	5526	4878	4384	3900	4662	1400	2800	6400
Eggs									21000				2100
Total COGS	9200	5519	8437	7166	6132	5526	4878	4384	24900	4662	1400	2800	8500
Gross Margin	115800	-5519	89063	67834	31368	19224	15122	9616	-12900	95295	-1400	-2800	42070
Expenses													
Labor	5250	5250	5250	5250	5250	5250	5250	5250	5250	5250	5250	5250	6300
Selling Expenses													
Telephone	167	167	167	167	167	167	167	167	167	167	167	167	200
Rent	33	33	33	33	33	33	33	33	33	33	33	33	40
Heat	2133	2133	2133	2133	2133	2133	2133	2133	2133	2133	2133	2133	2560
Electrical Service	2500	2500	2500	2500	2500	2500	2500	2500	2500	2500	2500	2500	3000
Travel & Vehicle	167	167	167	167	167	167	167	167	167	167	167	167	200
Maint. Tanks, Bldg, Ground	417	417	417	417	417	417	417	417	417	417	417	417	500
Chemicals, Nets, Boots, et	500	500	500	500	500	500	500	500	500	500	500	500	600
New Equip & Misc.	10000												1000
Total Operating Expenses	21167	11167	11167	11167	11167	11167	11167	11167	11167	11167	11167	11167	14400
Operating Profit	94633	-16686	77896	56667	20201	8057	3955	-1551	-24067	84128	-12567	-13967	276703
Cashflow Bfore Debt Service	94633	-16686	77896	56667	20201	8057	3955	-1551	-24067	84128	-12567	-13967	
Cumulative Cashflow	94633	77948	155844	212511	232713	240770	244725	243175	219108	303236	290670	276703	

APPENDIX B

"Development of Thermally Enhanced Walleye Aquaculture Monthly Reports"

September 1987 - January 1988

Development of Thermally-Enhanced Walleye Aquaculture

Monthly Report for September 1987

Principal Investigator: Michael McDonald, Ph.D.

Initially, walleye already converted to artificial feed were to be purchased from a commercial dealer. However, the dealer was unable to convert enough of his walleye to meet project needs. Iowa DNR's Rathbun Fish Hatchery was then contacted to obtain converted walleye. However, the hatchery personnel considered their converted walleye too valuable to their stocking programs to provide this project with the necessary experimental fish. It was then decided to purchase the smallest walleye fingerlings available and convert them to artificial feed at ARF. Fish obtained through Leech Lake Reservation's Dept. of Fisheries would also be used to supplement this supply. Although there is increased risk involved with this late season conversion of walleye fingerlings, the potential gain of useful project information is also increased sufficiently to make the risk acceptable.

Artificial feed for the walleyes was obtained from Glencoe Mills and delivered to ARF on September 14. The ARF facility became fully operational during the week of September 21. Approximately, 5000 four inch walleye fingerlings were obtained from Gulden Pond Fisheries (Erskine, MN) and delivered to ARF on September 30. Prior to this time, water temperature at ARF was lowered to 64° F (as low as possible - ambient river temperature) to reduce thermal stress on walleye fingerlings (taken from 52° F water). A 17% mortality of this group occurred within 1 day, likely due to stress from handling, transportation, and temperature change. Delivery of an additional 1500 walleye fingerlings from Leech Lake Reservation's Dept. of Fisheries was expected (and occurred) on Friday October 2.

During this period the walleye bioenergetics model was further refined and partially parameterized for expected conditions at ARF. A hard disk drive was obtained (no cost to MP) and the model was transferred to it. This will increase the capacity of the model and will speed modelling simulations.

Development of Thermally-Enhanced Walleye Aquaculture

Monthly Report for October 1987

Principal Investigator: Michael McDonald, Ph.D.

At the end of October we had approximately 3900 walleye fingerlings remaining from an initial starting population of about 6250. The >60% survival of these fingerlings to this point is excellent, especially considering the large initial size of the fingerlings and the initial stocking stresses. We had a large scale fungal infection shortly after stocking, but this was rapidly controlled by administering antibiotics to the tank water. We then discontinued antibiotic use, and since then, we have been treating tanks daily with a salt solution as a prophylactic. Antibiotics (tetracycline) are used on an as needed basis, when fungal infections are observed.

During October, the walleye fingerlings began to eat the artificial feed and are now consuming the intermediate W-16 diet pellets (3/32"). On Saturday, October 16, at a critical point in the walleye's switch over to artificial feed, the single power generation unit in operation was shut down. Quick action by ARF operators was taken to temper the fishes slowly (at about 2° F/hr) from facility operational water temperature (68° F) to ambient river temperature (42° F). Unit 3 came back on line on Sunday, and ARF personnel began the process of slowly re-acclimating the walleye to 68° F). Walleye were back at normal temperature by the afternoon of October 20. However, walleye were not being fed during this entire period. This may have resulted in increased mortality from thermal stress, susceptability to disease in the stressed fish, and/or loss of conversion of some fish to artificial feed. This delayed the conversion of the walleye fingerlings to artificial feed, such that the initial conditions for parameterizing the bioenergetics could not be obtained during October. Thus, simulation predictions from the walleye bioenergetic model will be made based on initial conditions taken during sampling in November after the majority of starvation mortality has occurred.

In October, we did succeed in accomplishing one of our research objectives. This was to determine whether large, wild-caught walleye fingerlings could be converted to feeding on artificial food. In examining the feeding tracts from several specimens in tanks at ARF, we have found them to be full of food. Also, the robust condition of most of the remaining fishes and the nature of the fecal matter in the tanks suggests that, we have indeed succeeded in converting these larger walleye.

Current ARF operation has been modified to a 6-day feeding schedule (no Sunday feeding), with a daily 16 hr light and 8 hr dark cycle. Feeding occurs during the low level light period from 4 pm to 8 am. Fish are being fed at an estimated 5% body weight/da. Water temperature has been increased to 70° F, as long as nitrogen supersaturation does not exceed 105%.

Walleye bioenergetics model is now fully operational on the hard disk drive. The model has been further refined, and now only requires the initial ARF fish parameters to begin predictive simulation. Growth predictions from the model will be compared to actual observed growth for November.

Development of Thermally-Enhanced Walleye Aquaculture

Monthly Report for November 1987

Principal Investigator: Michael McDonald, Ph.D.

At the end of October we had 3904 walleye fingerlings, and at the end of November we had 2611 walleye remaining. This is a 67% survival rate for November. This is lower than we would have liked, but we continued to have starvation mortalities throughout November. Under these conditions, this survival rate is reasonable, and mortalities dropped considerably by the end of November. In early November, walleyes in the initial 3 tanks were divided among 6 tanks. At this time the average fish weighed 11.1 g. Thirteen days later, from a subsample of fishes from three of the tanks, the average fish weighed 13.6 g (range 11.11-16.86 g). This is a 22.6% increase in body weight in less than 2 weeks in feeding fishes. Using a starting weight of 11.1 g, the current bioenergetics model predicted a weight of 15.6 g at the end of this 13 da period. While this is higher than the average observed weight, it does fall within the observed range. This suggests that with further actual data from the facility to parameterize and refine the model, that the model can be an efficient predictor of walleye growth under existing ARF conditions.

During November, the walleye fingerlings continued to eat the commercial W-16 diet pellets (3/32"). Feeding rate was maintained at 5% body weight/da. Feeding regime consisted of fish being fed for 16 hrs/da, 6 days/wk. Temperature was maintained at 69° F.

Fungal infection continued to be a problem in November. The use of antibiotics was required every 10-14 da. We have since gone to the prophylactic use of antibiotics, treating fishes for 4 da/wk. This is a more expensive treatment than has been previously used, but we feel it is necessary to maintain the fish in good health. In the future, the installation of an ultraviolet disinfection system on the incoming Mississippi River water, would likely reduce the need for continued antibiotic application.

In November, we succeeded in accomplishing several of our research goals. We were able to induce large, wild-caught walleye fingerlings to feed, and <u>grow</u> in ARF. Also, our predictions of initial walleye growth from the bioenergetics model appear to agree quite well with the observed growth, especially at this early stage of model refinement. Based on the current model, the predicted average weight of a walleye by the end of December is 30 g. The model is currently being refined based on the new data, and a revised December walleye growth estimate will be made.

Much of the successful rearing of the walleye in ARF to date, has been determined by the high quality of the MP personnel at ARF. They have been exceptional at responding to emergencies (real and otherwise) at all hours of the day and night, seven days a week. The should be commended for their diligence.

Development of Thermally-Enhanced Walleye Aquaculture

Monthly Report for December 1987

Principal Investigator: Michael McDonald, Ph.D.

At the end of November we had 2611 walleye fingerlings, and at the end of December we had 2529 walleye remaining. Only 82 fish were lost during this period for a monthly mortality rate of 3.1%. Some disease and starvation mortalilty continued into the first week of December. With the prophylactic use of tetracyclene for disease control on the fingerlings, mortalities in the last three weeks of December were reduced to 26 fish.

Fingerling walleye at ARF weighed an average of 20.81 g on December 17, 1987. This is an increase of 7.21 g from the previous measurement on November 17, 1987. This is a weight increase of 53% in one month.

Using the November 4, 1987 fingerling weight (11.1 g) as the initial weight of the fingerlings and the November 17, 1987 weight as another data point, the current walleye bioenergetics model was used to predict a weight of 20.85 g for fingerlings on December 17, 1987. The average of the observed weights for the fingerlings in ARF at this time was 20.81 g (Fig. 1, Table 1). Under ambient field temperature conditions during this period, walleye fingerlings would show no growth (Fig. 1, Table 1). If the fingerlings were maintained under ARF conditions, but fed 7 days a week (rather than the current 6 days), predicted fingerling size at this time would have been 28.43 g (Fig. 1, Table 1). The predicted weight of walleye fingerlings, under current ARF regimen, for January 17, 1988 is 30.54 g (Fig. 1, Table 1).

During November, the walleye fingerlings continued to eat the commercial W-16 diet pellets (3/32"). Feeding rate was maintained at 5% body weight/da. Temperature was maintained at 69° F.

Current predictions of walleye growth from the bioenergetics model appear to agree quite well with observed growth. Since disease and starvation have been reduced to current low levels, the necessary data can begin to be acquired to improve the predictive capability of the model for estimating mortality over a growth period, as well as, estimating the feed consumption of the fingerlings over a growth period.

Much of the successful reduction in disease of the walleye in ARF has been due to a conscientious and determined effort on the part of MP personnel at ARF. Their efforts have brought the mortality down to the currrent low levels.

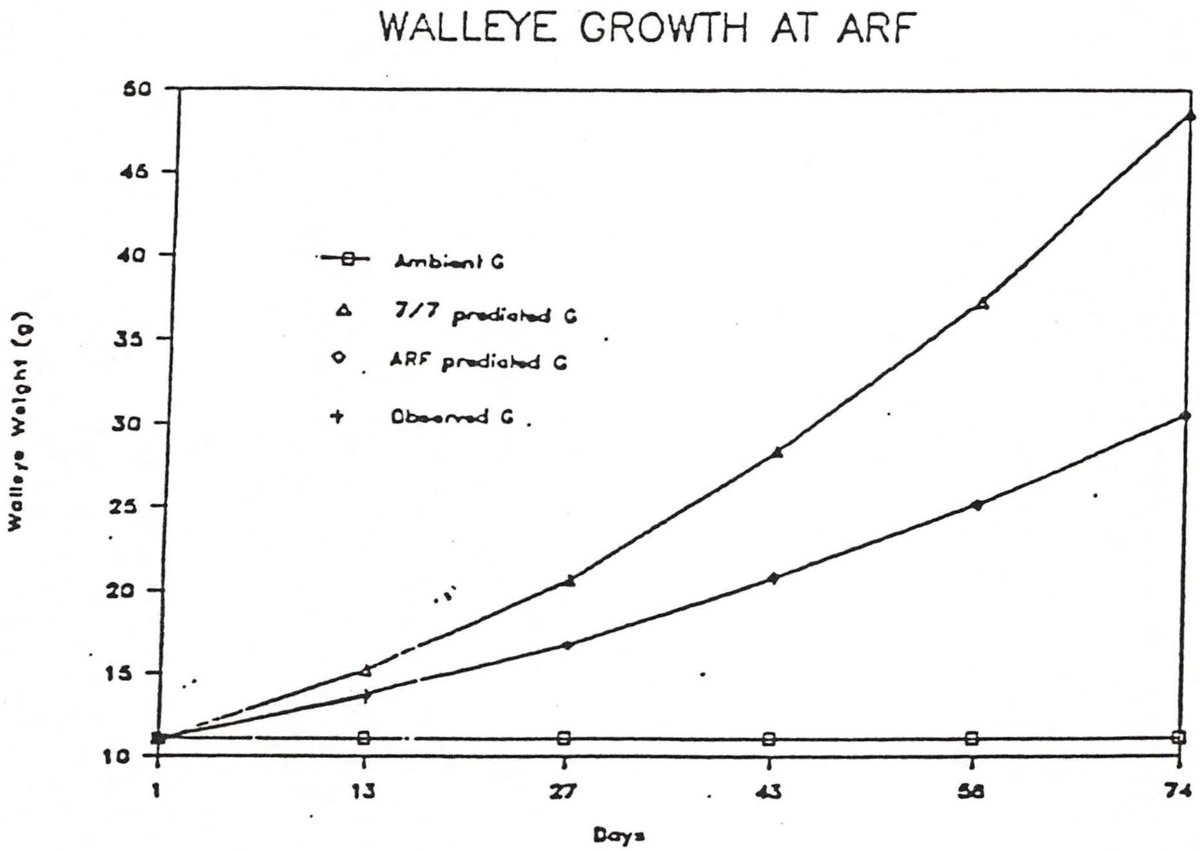

Figure 1. Observed (Observed G) and predicted size of walleyes in ARF starting on November 4, 1987 (Day 1). Predicted walleye sizes are from the bioenergetic model using ambient winter water temperature (Ambient G), current ARF conditions (ARF Predicted G), and at current ARF conditions, but fed 7 days/week (7/7 predicted G).

Date	Day	Amb. G	Obs. G	Pred. G	7/7Pred.
4Nov87	1	11.1	11.1	11.1	11.1
17Nov87	13	11.1	13.6	13.74	15.21
1Dec87	27	11.1		16.76	20.69
17Dec87	43	11.1	20.81	20.85	28.44
1Jan88	58	11.1		25.24	37.29
17Jan88	74	11.1		30.54	48.62

Table 1. Observed (Obs. G) and predicted size of walleyes in ARF starting on November 4, 1987. Predicted walleye sizes are from the bioenergetic model using ambient winter water temperature (Amb. G), current ARF conditions (Pred. G), and at current ARF conditions, but fed 7 days/week (7/7 pred.).

Development of Thermally-Enhanced Walleye Aquaculture

Monthly Report for January 1988

Principal Investigator: Michael McDonald, Ph.D.

We had only 4 walleye mortalities during the month of January. During the period from 20 Jan - 22 Jan, a total count of all the walleye fingerlings in all tanks was made. We have a total of 2474 fish currently in the facility. This is 50 fish less than we previously estimated, but was based on the propagation of a less than 1% error in our initial density estimate. Therefore our actual mortality during the month of January was 0.2%. We have continued our prophylactic use of tetracycline for disease control. (Oxy)Tetracycline has been cleared for use in food fish by the U. S. Food and Drug Administration since 1976 (Meyer, F. P., Schnick, R. A., Cumming, K. B., and Berger, B. L. 1976. Registration status of fishery chemicals. Progressive Fish Culturist 38(3)). As of 1986, it was one of only five chemicals which were registered for use (Stickney, R. R. 1986. Culture of Nonsalmonid Freshwater Fishes. CRC Press).

Fingerling walleye at ARF weighed an average of 28.3 g on January 17, 1988. This is an increase of 7.5 g from the previous measurement on December 17, 1987. This is a weight increase of 36%. The walleye bioenergetics model predicted a weight of 30.5 g for fingerlings on January 17, 1988 (Fig. 1, Table 1). Walleye growth was also predicted for ambient field temperature conditions during this period, and for ARF conditions when fed 7 days a week (rather than the current 6 days). The model overestimated the average walleye growth during this period by approximately 7%. This difference may be due to differences in growth of the two strains currently being used in ARF. The Leach Lake strain's average walleye weight on 17 January was estimated 35.9 g, while the Erskine strain's average fish weight was estimated as 24.5 g. I feel that the previous use of a mean weight for fishes may have introduced some error into the model's predictive capabilities. I intend to begin to develop models for each of these strains to obtain better predictive capabilities and to be able to compare growth rates between the strains for future stock enhancement.

During mid-December, the walleye fingerlings were switched to a 1:1 mix of 3/32" and 1/8" W-16 diet pellets; feeding rate was reduced to 3% body weight/d, because of the larger size of the fingerlings. Temperature was maintained at approximately 69° F.

Walleye fingerlings were redistributed within their tanks, maintaining strain integrity, such that the current densities in the tanks is between 408-420 fish/tank. This will allow better tracking of the feeding and food consumption for use within the bioenergetics model.

The continued successful reduction in mortality of the walleye in ARF has been due to a conscientious and determined effort on the part of MP personnel at ARF. Their efforts on behalf of this project are invaluable.

Date	Day	Amb. G	Obs. G	Pred. G	7/7Pred.
4Nov87	1	11.1	11.1	11.1	11.1
17Nov87	13	11.1	13.6	13.74	15.21
1Dec87	27	11.1		16.76	20.69
17Dec87	43	11.1	20.81	20.85	28.44
1Jan88	58	11.1		25.24	37.29
17Jan88	74	11.1	28.3	30.54	48.62
1Feb88	84	11.1		34.2	56.8
17Feb88	101	11.1		41	72

Table 1. Observed (Obs. G) and predicted size of walleyes in ARF starting on November 4, 1987. Predicted walleye sizes are from the bioenergetic model using ambient winter water temperature (Amb. G), current ARF conditions (Pred. G), and at current ARF conditions, but fed 7 days/week (7/7 pred.).

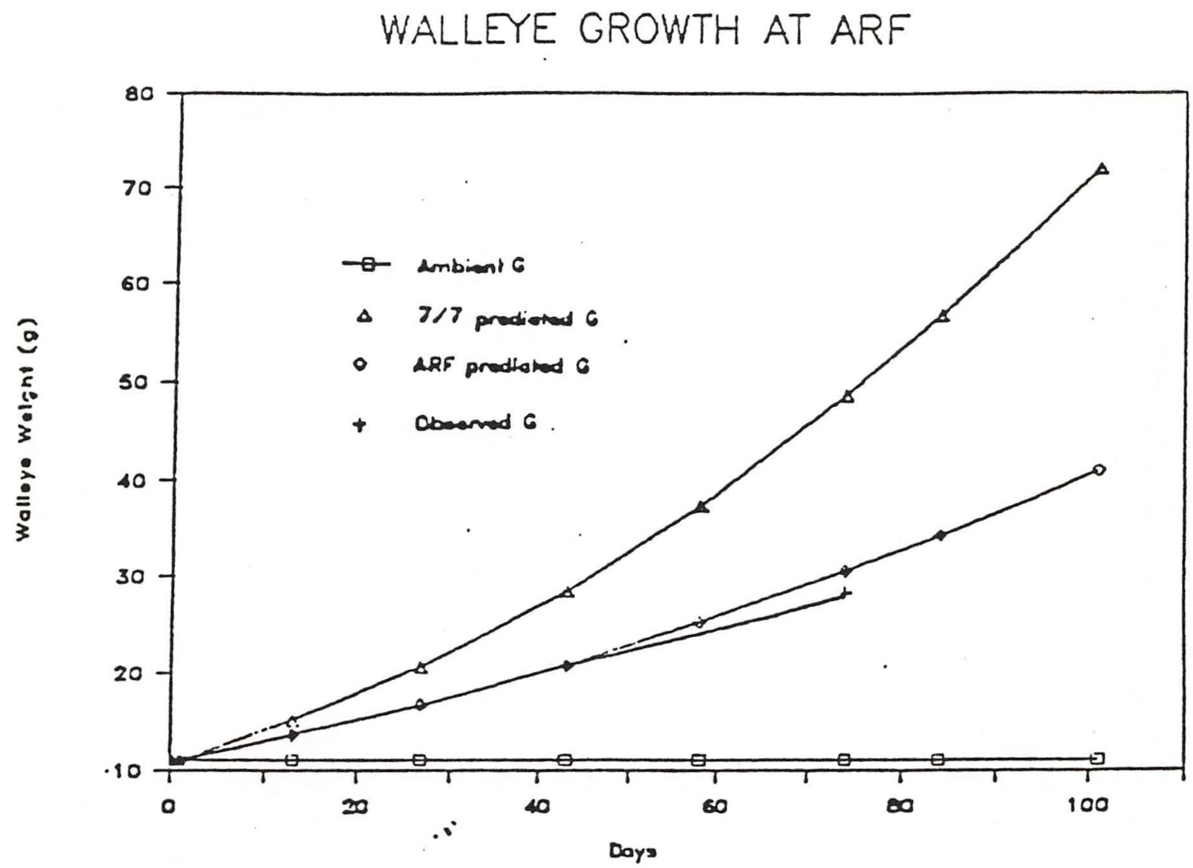

Figure 1. Observed (Observed G) and predicted size of walleyes in ARF starting on November 4, 1987 (Day 1). Predicted walleye sizes are from the bioenergetic model using ambient winter water temperature (Ambient G), current ARF conditions (ARF Predicted G), and at current ARF conditions, but fed 7 days/week (7/7 predicted G).

APPENDIX C

"Development of Thermally Enhanced Walleye Aquaculture"

A July 21, 1987, Proposal to Minnesota Power
by Michael McDonald

Development of Thermally-Enhanced Walleye Aquaculture

A proposal to Minnesota Power

from:

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July 21, 1987

INTRODUCTION

A major obstacle in the development of aquaculture in northern Minnesota is the slow growth of cultured species in cold water. The primary growing season in this area may only be 4-5 months. The growing season can be extended and growth rates can be increased in northern climates by heating the water. However, costs associated with heating the water of a culture facility to optimal growth temperatures are often prohibitive (see McDonald et al. 1987).

Recently, using the thermal and water resources of Minnesota Power's Clay Boswell Steam Electric Station (CBSES), channel catfish, rainbow trout, Atlantic salmon (Minnesota Power and Minnesota Department of Natural Resources Report 1986), and whitefish (J. Ringle, Leech Lake Tribal Fisheries Biologist, personal communication) have been successfully reared in the Aquaculture Research Facility (ARF). Economic scaling of costs involved with growing Atlantic salmon and catfish suggests that a moderate return on invested capital could be obtained on a full scale aquaculture operation for these species (P. Johnson, Minnesota Power, personal communication). However, market saturation of Atlantic salmon by the early 1990's and the existing southern U.S. catfish aquaculture infrastructure may seriously hinder market penetration for new growers of these species.

Thermally-enhanced aquaculture of walleye in Minnesota could develop into a major, new growth industry. Demand for walleye will continue to increase due to increasing demand for walleye stocking in sports fisheries and increasing consumer demand

(Skurla and Van Hale 1987). The sport fishing and consumer market already recognizes the walleye as a high value fish.

The walleye is an appealing aquaculture species because of its high market value and because it can be marketed at several different life stages. Currently, the existing markets for walleye are: 1) as eggs for hatcheries (at \$400-\$1000 per quart), 2) as fry for stocking (at \$16-\$25 per 1000), 3) as 2" fingerlings for stocking (at \$0.15-\$0.25 apiece), 4) as wholesale round weight fish (at \$1.25-\$3.00 per pound), and 5) as a fillet for the retail consumer (at \$3.25-\$6.00 per pound) (Skurla and Van Hale 1987).

Simulations of walleye growth in facilities with heated and unheated waters, based on a walleye bioenergetics model (McDonald unpublished data), suggests that in the heated water facility growth would be 4-fold faster, survival 3-fold greater, and food conversion 30% better. Using heated waters appears to offer a substantial benefit in producing a marketable product faster and more efficiently than could be obtained with current (unheated) techniques. Also, this opens possibities for producing multiple walleye crops during the year (varying temperature to speed up or retard the growth of the fish), and to bring the particular product to market at the most profitable time.

To develop the full potential for walleye culture, both the biological and economic opportunities and constraints must be examined (see Skurla and Van Hale 1987). For a successful venture, further research is necessary to: 1) develop suitable feeds and culture techniques for intensive culture of walleye fry to the fingerling size, 2"(a biological bottleneck see Nickum 1978,1985); 2) assess the survivorship of 2" fingerlings stocked into lakes earlier (because of increased growth in the heated water) relative to the current walleye survivorship (biological aspects of future market development); 3) assess the growth, survivorship, and food conversion of fingerling walleye during grow-out to consumer-size, under thermally-enhanced, intensive culture conditions; 4) further develop and refine walleye bioenergetic models to allow the simulation of various potential changes in culture conditions; and 5) further assess the business and economic variables associated with the operation of a walleye aquaculture facility and the marketing potential for various walleye products.

WALLEYE BIOENERGETICS MODEL

The existing walleye bioenergetics model was developed from a generalized bioenergetics model (Hewett and Johnson 1987), to predict changes in growth or food consumption under different thermal or cultural regimes. The general model has been used extensively, and successfully, for predicting consumption or growth of a variety of species in natural systems (e.g., Kitchell et al. 1977, Kitchell and Breck 1980, Stewart et al. 1981, Cochran and Rice 1982, Rice and Cochran 1984), and has recently been used for estimating growth of chinook salmon under various culture conditions (McDonald et al. 1987). Bartell et al. (1986) have examined the sensitivity of this model to individual parameter perturbation to identify key variables, which may greatly affect the model's outputs.

Physiological parameters for the walleye model were taken from Kitchell et al. (1977) for walleye in Lake Erie. Growth rates in warm water were extrapolated from Grinstead's (1971) work with walleye in Oklahoma reservoirs. Mortality rates (45%), food availability (67% of maximum daily consumption, determined iteratively from growth end points), food caloric content (1000 cal/g wet wt), and temperature (21° C, assumed for ARF) were all assumed to be constant over the entire year. Current simulations based on this walleye bioenergetics model suggest that at the end of six months in the ARF facility, a 15 g walleye fingerling will have reached approximately 300 g (0.6 lb).

PROPOSAL

Given the initial success of ARF at CBSES, I propose, in collaboration with Minnesota Power personnel, to examine the feasibility of thermally-enhanced, intensive culturing of walleye fingerlings. This study would assess: the potential for growth, survival, and food conversion of walleye fingerlings under optimal temperature conditions at the ARF facility. This would establish the initial feasibility for walleye production at ARF. Growth rate, survival, and food conversion efficiency found during the study would be compared with the estimates from the walleye bioenergetics model, and the model revised. The model may be extremely useful in subsequent optimization of walleye fingerling production. The study would begin in early September.

PROPOSED CULTURE CONDITIONS

Intensive culture of pond-reared walleye fingerlings is relatively new (Nickum 1985), but walleye fingerlings have been reared on formulated diets for at least the last 15 years (see

Cheshire and Steele 1972). Conversion of walleye to pelletized food has been most successful, if the fish are approximately 50 mm (Nickum 1978). Small walleye fingerlings will not be available in September, and unnecessary mortality may occur in trying to convert large, wild harvested walleye to pelletized food. Therefore, fingerlings will be obtained from a commercial dealer, and will already have been converted to a pelletized feed.

Currently, 25 kg m^{-3} is considered the maximum stocking density for walleye fingerlings (Nickum 1985). I propose stocking 300 fingerlings in each of the existing 8 tanks (2400 fingerlings). This density would be 5-7 kg m^{-3}. This will allow for substantial growth of the fingerlings prior to any culling.

There are no published production level studies on feeding rates and feed conversion ratios for walleye fingerlings (Nickum 1985). Fingerlings fed to satiation in experimental studies have consumed food at rates of 5-10% of their body weight daily, and food conversions as low as 1.5 have been obtained (Nickum 1985). Therefore, I propose to initially begin feeding of fingerlings at 5% of their body weight, and after one week, adjust the feeding level. Amount of feed will be adjusted every week to allow for increasing body weight. Survivorship during this period will likely be at least 60%, but may be as high as 80-99% (Nickum 1985).

U. S. Fish and Wildlife Service's W-16 cool water fish diet (manufactured by Glencoe) has been used successfully to grow walleye fingerlings (Nickum 1985). I propose using the W-16 diet (or a similar feed, depending on availability). Initially, automatic feeders will dispense food at 5 minute intervals during the light period. This will be subsequently adjusted depending on observed food usage (previous work suggests food should be provided at 2-10 min intervals, see Nickum 1985). A 16-24 hr period of dim light has been suggested for good walleye growth (Nickum 1985). Therefore, I propose using a 16 hr period of relatively low light intensity daily.

Optimum temperature for walleye fingerling growth has been experimentally determined to be between 22° C (Smith and Koenst 1975) and 26° C (Hokanson and Koenst 1986). Huh et al. (1976) obtained good growth and a gross food conversion rate of 1.62 for walleye fingerlings cultured at 22° C. Therefore, I propose to use a water temperature of 22° C to culture the fingerlings.

Walleye appear to be relatively tolerant of a wide range of dissolved oxygen concentrations (as low as 2 ppm, Scherer 1971). However, dissolved oxygen should be maintained above 5 ppm in order to reduce stress in intensive culture. The pH of the culture water should be maintained between 6 to 9, as this is the range that walleye are typically found in nature (Scherer 1971). The culture water for walleye fingerlings should be exchanged 3 - 5 times hr^{-1} with heavy stocking densities or high feeding rates (Nickum 1985). Thus, I propose 3 complete water exchanges hr^{-1}. As a conservative estimate, dissolved gases should not exceed 100% saturation, and ammonia (un-ionized) should not exceed 0.0125 ppm in the culture system (see Piper et al. 1983).

Optimal rearing conditions and diets have not been developed for post-fingerling walleyes, but they will continue to grow year-round if water temperatures above 20° C are available (Nickum 1985). Generally, in the absence of other information, fingerling production methods are adequate for the rearing of post-fingerling walleyes (Nickum 1985).

Walleye remaining at the end of the study period will either be used to test consumer acceptance of the taste of cultured walleye, or will be stocked into lakes chosen by Minnesota Power in conjunction with Minnesota DNR. We intend to tag all released fishes to assess their growth and survival after stocking, and to assure no deleterious effects of thermal rearing.

This research is the requisite first step in the development of thermally-enhanced, intensive culture of walleye in Minnesota. It will provide data on the growth, survivorship, and food conversion of walleye grown intensively under ideal thermal conditions. It will also yield insights into the utility of further research on walleye cultured in heated water at ARF and similar facilities. In addition, it will allow further refinement, and increase the predictive capacity, of the bioenergetics model for walleye fingerlings and adults, which is desirable for initiating new aquaculture operantions and enhancing possibilities for production at ARF.

DELIVERABLES

1. Final report with growth, mortality, and feed conversion for the walleye at ARF during the study period and future study/facility recommendations.

2. Revised bioenergetic model projections for walleye growth and food consumption in thermally-enhanced intensive culture, based on actual facility operations, for future application in

ARF or elsewhere.

3. Development of a joint research (e.g., NRRI, MN Power, Leech Lake Reservation Fisheries Program, MN DNR) proposal for multiple funding sources to continue development of an economically and biologically viable, thermally-enhanced, intensive walleye aquaculture venture.

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APPENDIX D

Minnesota Stocking Survey

Cover Letter
Survey Form
Survey Results

Center for Economic Development

UNIVERSITY OF MINNESOTA
DULUTH

Natural Resources Research Institute Business Group
150 School of Business and Economics
10 University Drive
Duluth, Minnesota 55812-2496

(218) 726-7946

October 23, 1987

Dear Club or Organization Member:

As Minnesotans who enjoy the outdoors we are all concerned with enhancing both the fish and wildlife population and our outdoor experience. Because of this concern and newly enacted Minnesota legislation, there has been an increase in interest by individuals in developing private aquaculture or fish rearing businesses in Minnesota.

The University of Minnesota, Duluth Center for Economic Development is currently identifying the potential markets for these aquaculture businesses. We need your help. Many clubs and organizations have active fish stocking programs or are interested in starting one.

Please take a few minutes and complete the enclosed survey. It deals with your involvement in any past stocking activity or future stocking activity. Also on the back of the survey we have left space for you to comment on your and the State stocking programs. The information and comments you provide will help us in our market assessment and may provide more stocking options for Minnesotans in the future.

Please complete <u>both</u> sides of the survey and return it by NOVEMBER 15, 1987 in the enclosed envelope. No postage is necessary. If you have any questions call Jim Skurla at (218) 726-8542. Thank you in advance for your help and cooperation.

Sincerely,

Jim Skurla

Jim Skurla
Business Development Specialist

MINNESOTA FISH STOCKING SURVEY

PLEASE COMPLETE BOTH SIDES OF THE SURVEY AND RETURN BY NOVEMBER 15, 1987 IN THE ENCLOSED ENVELOPE. NO POSTAGE IS NECESSARY.

1. Did your Club or Organization STOCK any species of fish in public or private Minnesota waters in 1987?

   Yes ______ No ______

2. Name of Club or Organization ____________________ Address ____________________
   telephone ______________

3. Please complete the following table for the fish stocked.

SPECIES OF FISH	NUMBER	SIZE	POUNDS	PRICE PAID

4. Was your stocking the same as in previous years?

   Yes ______ No ______

   If NO, how did your stocking experience compare to 1987.

   _____Stocked MUCH MORE in the past.

   _____Stocked SOMEWHAT MORE in the past.

   _____Stocked SOMEWHAT LESS in the past.

   _____Stocked MUCH LESS in the past.

5. SOURCE of fish for stocking.

NAME OF HATCHERY OR WATERS	CITY & STATE

6. DESTINATION of stocked fish.

NAME OF HATCHERY OR WATERS	COUNTY & STATE

(OVER)

7. Would your Club or Organization be interested in obtaining fish at competitive prices?

Yes _____ Contact Person______________________________ Telephone_______________

SPECIES OF FISH	NUMBER	SIZE	PRICE
------------------	------------------	------------------	------------------
------------------	------------------	------------------	------------------
------------------	------------------	------------------	------------------

No ______ Why not? ______________________________

8. Would your Club or Organization be interested in obtaining fish that have been converted to an artificial diet?

This will allow the fish to be fed fish feed instead of relying on natural food, such as minnows.

Yes _____ Please complete the following table.

SPECIES OF FISH	NUMBER	SIZE	PRICE
------------------	------------------	------------------	------------------
------------------	------------------	------------------	------------------
------------------	------------------	------------------	------------------

No ______ Why not? ______________________________

9. Please make any comments about your or the State stocking programs.

RETURN TO: UMD CENTER FOR ECONOMIC DEVELOPMENT, 150 SBE, 10 UNIVERSITY DRIVE, DULUTH MN. 55812

SUMMARY OF MINNESOTA STOCKING SURVEY

The Minnesota Stocking Survey was mailed to 301 clubs and organizations throughout the State. The mailing list was compiled from files and lists of the Department of Natural Resources and Minnesota Sea Grant. There were nine survey questions plus space for comments.

The response rate was nearly 12 percent. Of the 36 surveys that were returned, one club had folded and another has been inactive for a number of years. In addition, none of the surveys were completely filled out. Only selected parts of questions were completed, therefore to be conservative, estimated percentages are determined using the total returns of 36 surveys.

Only about 14 percent or five respondents provided information about the fish they had stocked in public or private waters during 1987. Two groups stocked, in total, less than 5,000 walleye ranging in size from 3 to 8 inches. Northern Pike was also planted by two respondents. One club stocked 1,350 muskie valued at $8,775, while another group planted a few thousand smallmouth bass in 1987.

When asked to compare their 1987 experience with previous years, 14 percent of the total respondents reported it was the same as previous years. Eight percent indicated that it was much more or somewhat more than in the past. About three percent revealed they stocked much less in the past and another three percent had stocked none in the past.

The source of the stocked fish was given by 17 percent or six of the respondents. Four reported Minnesota sources and the remaining two used Wisconsin growers as their suppliers.

Nineteen percent of the respondents revealed the destination of the fish. A total of six Minnesota and one Wisconsin counties were mentioned. The Minnesota counties included Douglas, Fairibault, Kandiyohi, Ottertail, Pine, and Wright. The Wisconsin county was Waukesha.

When asked whether their club or organization would be interested in obtaining fish at competitive prices, 36 percent or 13 respondents indicated interest by providing names and telephone numbers of contact persons. But only six percent expressed an interest in obtaining fish that had been converted to an artificial diet.

From the comments section of the survey, there appears to be a fairly even split opinion about the quality of the State stocking programs. Some respondents said they thought the State did a poor job, while others wrote that there good stocking programs and they are active participants. Another repeated comment was that clubs or organizations have limited funds and many would like to do more or some stocking but just don't have the money for permits and fish.

CONCLUSIONS

The market for stocking fingerlings in Minnesota is relatively small because Minnesota DNR tightly controls the state stocking programs and provides its own fish. In addition, the clubs around the state are generally small and financially strapped. Therefore, any Minnesota aquaculture operation will have to locate and be able to distribute to outstate customers.

PROPOSAL

MARKETING AND CULTURING WALLEYE IN MINNESOTA: A PROPOSAL

Prepared by:
James A Skurla
Thomas Van Hale

Natural Resources Research Institute
Business Group
Center for Economic Development[1]

and
Michael McDonald

Natural Resources Research Institute
Center for Water and the Environment[2]

March 1988

[1]The Center for Economic Development is a joint program of the UMD School of Business and Economics and the UMD Natural Resources Research Institute.
[2]The Center for Water and Environment is one of three Centers within the Natural Resources Research Institute.

CENTER FOR ECONOMIC DEVELOPMENT

UNIVERSITY OF MINNESOTA, DULUTH

OBJECTIVE

We intend to improve the economic potential for accelerated growth and improved survival of walleye fingerlings using warm water (from a steam electric generating plant). The integrated business and biological approach will be market driven and focus on reducing the costs of operation of an intensive walleye culturing facility and increase market development of Minnesota walleye.

BACKGROUND

An increasing demand for walleye for human consumption (table size) and for stocking in sports fisheries (eggs, fry, and fingerlings) has focused attention on commercial walleye production. But cold water and a short growing season (typically 4 to 5 months) are major obstacles to development of aquaculture in Minnesota. However, there is increasing evidence, however, to suggest that the use of heated water to extend the growing season and accelerate fish growth can enhance profitability and further the economic development of aquaculture in northern climates.

CURRENT MARKET AND BIOLOGICAL RESEARCH FINDINGS

Table walleye sold for human consumption are harvested from natural lakes with 90 percent imported from Canada. Walleye for stocking are raised commercially in Minnesota using extensive culture methods and fed natural diets, and generally, exported to other states. The profitability of this business, based on extensive culture, is uncertain because of production costs and variable survival.

Experimental grow out research, with an artificial food diet, suggests an intensive walleye operation using warm water improves the survival, growth rates, and time required to reach marketable size. Computer simulation models estimate that in heated water, walleye growth may be four times faster, survival three times higher, and artificial food conversion 30 percent better, than in unheated water.

PROPOSED RESEARCH ACTIVITIES

The integrated business and biological research would require three years to allow for brood stock life cycle development and sufficient replication for statistical assurance of production. However, some components can be completed in less time.

Business Research

The Business research will focus on the profitability and market development of the aquaculture facility. James A. Skurla and Thomas Van Hale, NRRI Business Group, would act as Co-Principal Investigators for this part of the project and would integrate the economic results with the biological research.

The objective is the completion of a business plan for ARF that is an analysis of finance, production, and marketing for a profitable strategy. The projected revenues are based on utilizing the facility to its load capacity and withdrawals of fish at regular intervals as predicted by the bioenergetics models. These sales projections need to be updated when load capacity, growth and survival rates are determined from continued operation and improved modeling. Analysis of economies of scale of facility sizes will be examined to estimate optimum scale of operation.

Another objective of both the business and biological research is to reduce operating costs of the intensive facility. The primary commercial competition for intensive fry and fingerling is extensive walleye operations. Every effort must be made to offset the potentially higher intensive culturing costs. A cost accounting system would be instituted to track operations and pinpoint possible methods for improvement in culturing techniques. For example, a precise raw materials and fish inventory analysis is essential for the most efficient cost controls. Food utilization is also important to keep feed waste to a minimum. Also transportation costs must be determined to evaluate if potential markets are too distant to be profitable. In addition, cost analysis of brood stock development cost is necessary to estimate the cost savings of holding brood stock over purchasing eggs or fingerlings at market prices. The brood stock cost would include any additional facilities that are needed, but would be offset by the sale of eggs that are not required by the facility.

Another focus of the business research will be market development, since the major market for commercially produced fish is outside Minnesota. States with large walleye sport fishing populations will be targeted. By withdrawing walleyes at monthly or regular intervals, revenues can be increased. But customers must be located to accept the fish deliveries. This will require an extensive market research effort in each target state. Profiles of walleye buyers will be developed. These profiles will include whether the purchase is public or private, the dates and quantities and sizes of walleye purchases, where they currently purchase their fish, and prices the buyer is willing to pay. The goal of the profiles is to obtain a large customer list that can be computerized, and mapped, to match the customer's buying preferences with the facilities's delivery timetables.

Outstate walleye buyers may be skeptical about the early market delivery of ARF raised fish because buying schedules are currently set by the availability of extensively raised fish. Delivery of fingerlings at the beginning of spring would allow for an entire summer's growth rather than the current practice of late fall stocking. This may require educating and adjusting the buyer to the new schedules. These early market fish should be very valuable, but the price is unknown and must be established.

Finally, artificially fed fingerlings may be more valuable than naturally or minnow raised ones. Rathbun Hatchery in Iowa found that artificially fed fingerlings are extremely valuable because of higher survival rates when stocked out. These claims need to be verified. But as a marketing tool, ARF fish may be marketed as a higher quality, and thus higher priced, because of greater survival and faster growth.

Biological Research

Michael McDonald, NRRI Center for Water and Environment, would act as Senior Principal Investigator for this part of the project with responsibilities to include coordination of Co-Principal Investigators and overseeing of the biological research components and coordination and integration of our findings with the Business Group. Co-Principal Investigators (subcontractors) are Anne Kapuscinski, Department of Fish and Wildlife, University of Minnesota-St. Paul, and John Ringle, Leech Lake Tribal Fisheries Biologist. Collaborators are Rick Barrows, U.S. Fish and Wildlife Service, and Robert Summerfelt, Iowa State University.

BROOD STOCK DEVELOPMENT THROUGH SELECTIVE BREEDING

The two strains currently on hand at the ARF will be monitored separately, for brood stock potential by examining the existing variation in numerous production traits. Examples of traits that will be measured include growth rate, food conversion, ratio of weight to length, flesh quality, age and size at sexual maturity, fecundity of females, egg size and quality, sperm viability, and disease resistance. This information will then be used to: (a) select the best individuals for breeding, and (b) design a mating scheme that will yield the greatest response to selection in the next generation. It may be possible to obtain viable gametes from some of the fish currently on hand at ARF when they reach two years of age (age 1 in May 1988), but substantial reproduction and selective breeding may not be possible until they reach three years of age.

Optimum performance of fry and fingerlings in captivity will be developed by selecting: against cannibalism, for successful gas bladder inflation, for pelleted food acceptance, and against deformities (e.g., of jaws and gill covers). Optimum performance of sub-adults and adults will be developed by selection: for fast growth rate, for good conversion of pelleted food, for body shape that yields high percent recovery in fillet weight, large egg size, and docile behavior. These lists of selected traits are not exhaustive and may be modified as knowledge about performance of walleye in intensive culture improves.

The breeding program will compare the performances of "purebred" and crossbred walleye by division of the program into two major components: first, selective breeding within each walleye strain so that matings will be made only between parents selected from the same strain; and second, selective crossbreeding between strains, so that matings will be made between a selected male from one strain and a selected female from the other strain. Crossbred progeny often show superior performance (hybrid vigor) compared to their parents, as has been shown by years of data collected from crossbred strains of livestock and the more limited data on crossbred fish strains.

Crossbred walleye may, therefore, contribute significantly to the genetic improvement of walleye production. This work will be subcontracted to Dr. Anne Kapuscinski, Assistant Professor, Department of Fisheries and Wildlife, University of Minnesota-St. Paul. This work will be conducted primarily by a graduate student under Kapuscinski's guidance (to maintain high research integrity and reduced cost). McDonald will also be a member of the student's graduate committee. Kapuscinski is currently collaborating on related research projects at the University of Minnesota-St. Paul (genetic engineering) and Iowa State University (R. Summerfelt, brood stock selection), which will allow enhanced data collection and provide rapid transfer of useful information. McDonald will use bioenergetics models to examine growth differences between strains under the various experimental conditions to allow for more direct assessment of possible genetic differences.

FRY AND FINGERLING FOOD DEVELOPMENT

Currently a major problem in the intensive culture of walleye is a suitable dry diet for fry. Also, to reduce production costs, improved fingerling diets need to be developed which will yield higher food conversion efficiencies. Currently, walleye are being fed U.S. Fish and Wildlife Service's W-16 walleye diet. The U.S. Fish and Wildlife Service is currently developing new and improved feeds for walleye, and we have been able to develop a collaborative arrangement with them to test some of these feeds (Dr. Rick Barrows, Walleye Diet Specialist, USFWS).

Walleye feeding experiments will be designed by McDonald in collaboration with Barrows. The research will be conducted by a graduate student under McDonald's direction (to insure research integrity, but reduce costs). McDonald will also use this data to develop bioenergetics models for walleye fry and will use the bioenergetics models to allow more direct comparisons of the diet studies being done by USFWS and at ARF.

DOCUMENTATION OF ENHANCED MARKET VALUE OF INTENSIVELY REARED WALLEYE

Recently, the Iowa DNR has conducted a study which suggests that their intensively reared fingerlings showed a 16 times greater survival after stocking than did pond reared fingerlings stocked into the same system. If this is the case, then intensively-reared walleye could command a significantly higher price than pond reared fish. However, this must be documented further and must be established for the walleye strains used at ARF before a market development strategy can be implemented.

We have reached a collaborative agreement with John Ringle, Leech Lake Tribal Fisheries Biologist, to re-stock ARF's Leech Lake walleye back into some of their lakes in the Leech Lake area when they are being stocked with extensively reared fingerlings. By tagging ARF walleye for individual identification we will be able to determine relative survival and growth of ARF fish relative to pond reared fingerlings. If successful, this could provide a tremendous marketing advantage for ARF intensively reared walleye. Ringle and McDonald will be responsible for establishing this field research program. Work will be carried out by the Leach Lake Tribal Fisheries staff under Ringle's direction. Results will be rapidly provided to the Business Group to incorporate into their marketing strategy.

PROPOSED BUDGET

	Year 1	Year 2	Year 3
Business Research			
I. ARF Operational Analysis	$ 8,000	$ 8,000	$ 8,000
II. Market Research	13,000	13,000	8,000
III. Integration of Business and Biological Research	4,000	4,000	4,000
Biological Research			
IV. Broodstock Development, Genetic Selection	25,000	26,500	27,500
V. Feed Development, Modeling, Coordination	45,000	42,000	40,000
VI. Stocking and Survivorship	25,000	26,500	27,500
	$120,000	$120,000	$115,000

Note: Budget does not include:

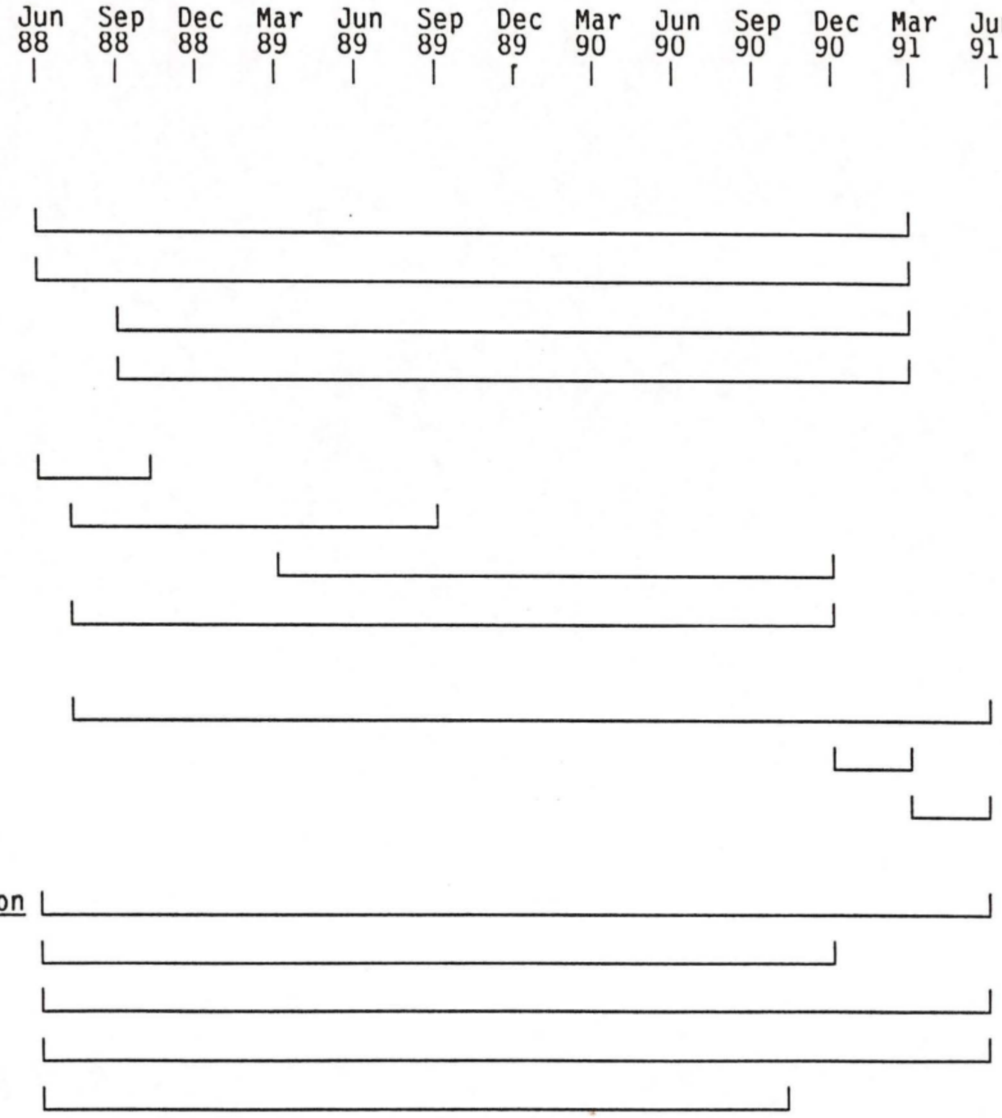
1) Indirect Costs previously charged off at 10 percent for Minnesota Power.

2) Minnesota Power personnel and facility use.

3) ARF facility upgrade.

4) Fish feed.

PROPOSED ACTIV SCHEDULE



<u>TASKS</u>

<u>Business Research</u>

I. <u>ARF Operational Analysis</u>

a) Revenue

b) Production Costs

c) Transportation Costs

d) Marketing

II. <u>Market Research</u>

a) Compile Buyer's List

b) Contact Buyers and Estimate Market Size

c) Estimate Delivery Schedule

d) Pricing Strategy--Estimate Value of Fish

III. <u>Integration of Bus. & Biol. Research</u>

a) Integration

b) Finalize Projections

c) Report Writing

<u>Biological Research</u>

IV. <u>Broodstock Development, Genetic Selection</u>

V. <u>Feed Development</u>

a) Modeling

b) Coordination

VI. <u>Stocking and Survivorship</u>

<u>Note</u>:

Business operation analysis is, in part, dependent on biological research, because revenue, production, and transportation costs will be derived from biological findings. The market research is independent of the biological research, with the exception of the estimating of fish delivery schedule.

The biological research is linked together in that each component builds on the others. However, each part can stand alone. Modeling will integrate the various components and allow for comparison.

Appendix C

Facility Personnel's Summary of Walleye growth
10-1-87 through 5-17-88

MEMO
EXCERPT
6/22/88 LWN

Finally, I would like to summarize and comment on the results of the current walleye growth experiment. Mr. R. E. Reardon and I have summarized the walleye growth data into several tables which are attached. Based on these results, I would not recommend that pellet fed intensively grown walleyes can be considered for a commercial operation at this time. Future research needs to be done to better define and refine production parameters.

In the present experiment, nearly one half (45%) of the fingerlings were lost while converting the fish to a dry diet (10/1/88 - 11/17/88). A higher success rate may be achieved by careful shipment, longer acclimation period before feeding and immediate antibiotic treatments to reduce infection (Table 1).

After initial losses due to stress related disease, walleye survival from mid-November through mid-May in all tanks has been greater than 80 percent which is excellent (Tables 2, 3 and 4).

The fingerlings have been fed in excess throughout the experiment which resulted in food conversion rates which are unacceptable for a commercial operation (Tables 5, 6 and 7). Throughout the experiment we have been feeding at 5% total estimated body weight which resulted in food conversions well above 2:1. Since mid-May we have dropped the feed rate to 2.5 % of body weight resulting in less waste food.

Table 8 summarizes the walleye growth from 11/17/88 through 5/17/88. Growth of both walleye strains has been approximately one-half inch per month which is commercially unacceptable. Growth was also variable from month to month. For example, the Cutfoot strain did not grow at all from 12/17/87 through 1/18/88, then increased over one inch from 1/18/88 through 2/18/88. This erratic growth pattern cannot be explained.

Future walleye research should address the following production parameters for this species to be considered in a commercial operation:

1) Successful survival conversion to dry diet should consistently be in the 70 to 80 percent range.

2) Growth in length should consistently be close to one inch per month.

3) Rearing densities in each raceway should be at least three lbs/ft^3.

4) Once converted to dry diet the food conversion ratio should be 2:1.

5) Several diets should be tried to determine if better and more consistent growth rates can be achieved.

6) Feed costs in excess of $0.40 per pound are too high. Investigate whether feed costs are production or ingredient related. Because walleye feed is not produced in large quantities (i.e. special orders) the high cost may be production related.

I hope that I have fulfilled your request for information. If you have any questions or require additional information, please call me at 328-6646.

LN:kms:c
cc: E. R. Kilpatrick
R. E. Lindholm
P. B. Johnson
File #2240

Info given to Mr. McDonald

TABLE 1

Total Numbers Of Fish

Tanks	10-1-8~~8~~7	11-17-88	11-17-88 % Survival thru Conversion
1 & 3	2174	973	45
2 & 4	2339	973	42
5 & 6	1711	834	49
	6224	2780	45

TABLE 2

Tanks 1 & 3

#Fish 10-1-8~~8~~7	stressed morts 10-1- to 10-14-87	% mortality
2174	864	40%

10-14-87	starved morts 10-14 to 11-17-87	% mortality
1310	338	26%

11-17-87	survivors 5-17-88	% survival
973	812	83%

TABLE 3

Tanks 2 & 4

#Fish 10-1-8~~8~~7	stressed morts 10-1- to 10-14-87	% mortality
2339	1169	50%

10-14-87	starved morts 10-14 to 11-17-87	% mortality
1170	197	17%

11-17-87	survivors 5-17-88	% survival
973	834	86%

TABLE 4

Tanks 5 & 6

	stressed morts	
#Fish 10-3-8~~8~~7	10-1- to 10-14-87	% mortality
1711	73	4%
	starved & fungus morts	
10-14-87	10-14 to 11-17-87	% mortality
1638	804	49%
	survivors	
11-17-87	5-17-88	% survival
834	811	97%

TABLE 5

Tanks 1 & 3

DATE	# FISH	TOTAL WT. (lbs.)	WT. INCREASE (lbs.)	FOOD FED (lbs.)	FOOD FED/ WEIGHT GAIN CONVERSION RATE
11-17	973	26.3	-	-	-
12-17	822	34.9	8.6	40.5	4.7:1
1-18	818	44.2	9.3	39.8	4.3:1
2-17	815	84.2	40.0	35.2	0.88:1
3-17	814	109.8	25.6	46.3	1.8:1
4-20	814	99.3	-10.5	66.8	-6.4:1
5-17	812	114.2	14.9	68.5	4.6:1

TABLE 6

Tanks 2 & 4

DATE	# FISH	TOTAL WT. (lbs.)	WT. INCREASE (lbs.)	FOOD FED (lbs.)	FOOD FED/ WEIGHT GAIN CONVERSION RATE
11-17	973	25.5	-	-	-
12-17	843	35.5	10.0	31.2	3.1:1
1-18	840	45.3	9.8	38.1	3.9:1
2-17	836	64.3	19.0	37.1	1.9:1
3-17	835	77.2	12.9	48.5	3.8:1
4-20	835	96.3	19.1	66.25	3.5:1
5-17	834	101.3	5.0	66.47	13.3:1

TABLE 7

Tanks 5 & 6

DATE	# FISH	TOTAL WT. (lbs.)	WT. INCREASE (lbs.)	FOOD FED (lbs.)	FOOD FED/ WEIGHT GAIN CONVERSION RATE
11-17	834	30.5	-	-	-
12-17	816	42.9	12.4	26.0	2.1:1
1-18	816	44.1	1.2	29.9	24.9:1
2-17	816	84.3	40.2	48.8	1.2:1
3-17	816	110.1	25.8	63.3	2.4:1
4-20	815	139.8	29.7	89.1	3.0:1
*5-17	811	157.1	17.3	96.4	5.6:1

*Tanks 5 & 6 were split evenly with tanks 7 & 8 on 5/3/88 (203 fish/tank).

TABLE 8

Erskine Strain (Tanks 1-4)

DATE	# FISH	TOTAL WT. (lbs)	AVE. WT. (oz.)	ESTIMATED* AVE. LENGTH	RATE (#/lb)	LB/FT^3
11-17	1946	51.8	0.43	4.1	37.2	0.19
12-17	1665	70.4	0.68	4.8	23.5	0.26
1-18	1658	89.5	0.86	5.1	18.6	0.33
2-17	1651	148.5	1.44	6.1	11.1	0.55
3-17	1649	187.0	1.81	6.6	8.8	0.69
4-20	1649	195.6	1.90	6.7	8.4	0.72
5-17	1646	215.5	2.09	6.9	7.7	0.79

0.47 in./month length increase

Cutfoot Strain (Tanks 5-8)

DATE	# FISH	TOTAL WT. (lbs)	AVE. WT. (oz.)	ESTIMATED* AVE. LENGTH	RATE (#/lb)	LB/FT^3
11-17	834	30.5	0.59	4.5	27.3	0.22
12-17	816	42.9	0.84	5.1	19.0	0.32
1-18	816	44.1	0.86	5.1	18.5	0.32
2-17	816	84.3	1.65	6.3	9.7	0.62
3-17	816	110.1	2.16	7.0	7.4	0.81
4-20	815	139.8	2.74	7.5	5.8	1.03
5-17	811	157.1	3.10	7.9	5.2	0.58

0.57 in./month length increase

*Lengths were estimated using length-weight tables available in Fish Hatchery Manual (Piper 1982).